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ORIGINAL ARTICLES.

I.—The Mechanism of Volcanic Action, being the Opening Address to Section III (Vulcanology) of the International Geographical Congress.

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(PLATES XXIV AND XXV, AND TEXT-PLATE.)

IN a discussion of this kind it is advisable to be as concise as possible, eliminating minor details, so as to give prominence to the main outlines of any theory one holds. This communication, which the Council of the Ninth International Congress of Geography have honoured me by asking me to address to you, I propose to put into the form of a 'credo'. To this I shall add a few fundamental facts upon which my reasoning was based, leaving minor ones for discussion at greater leisure elsewhere. For convenience I propose to divide my theory into two sections. In the first I shall review what may be conveniently called deep volcanic action, and in the second that group of phenomena that occur when igneous matter nearly reaches the surface or actually finds an exit thereon. Unfortunately, in the first case I am obliged to rely on hypotheses and deductions, whereas in the second section, that of superficial volcanic action, there are a number of fundamental facts and observations upon which to base speculation, and to which I propose to draw your attention.

Of one fact we are certain, and that is our globe is surrounded by a solid crust, which wherever it can be examined shows unmistakable and almost universal evidence of compression, wrinkling, and dislocation. This crumpling and crushing are equally inexplicable, unless we admit that since the initial solidification of the earth's crust its lower, still cooling part or support has undergone contraction so as to crowd together the already cooled burden of the upper part that this contracting mass carries.

No one has yet attempted to even suggest that the part of our globe subjacent to the solid crust has shrunk from other causes than a loss of heat. We may therefore look upon the idea of contraction as due to cooling to be a universally accepted fact.

In the old theory of the earth-crust crumpling over a contracting and cooling nucleus, fluid, or partially so, it always appeared to me to be inexplicable how fluid matter could be squeezed out, or why the water on the surface of the earth did not rush down to fill up the vacancy that the contracting interior tended to produce between itself and the arch of the crust. This perhaps is expressing the facts in simple commonplace terms, but is sufficient to illustrate the incompatibility of this hypothesis with the fact of some of the liquid interior of the earth rising through the fissures towards the surface and being squeezed out by the contracting crust.

The hypothesis that tangential thrust did not exist, but that the earth-crust was shrinking on an entirely or partially fluid nucleus, would have satisfied the vulcanologist, but is contrary to the incontrovertible evidence of tangential compression, as seen in the plications and overthrusts existing upon the entire surface of the globe, or at least that part above sea-level. This hypothesis was based upon the conception that the earth's crust was acting as a single unit.

To Messrs. Mellard Reade and C. Davison[1] is due the credit of making an analytical study of the functions of different parts of the earth's crust. That work demonstrated that theoretically we can divide the cooling surface of the earth into a series of shells. The outer shells that have reached approximately the mean atmospheric temperature will, of course, have stopped contracting, whereas the shells nearest to the heated nucleus will be those losing their heat most rapidly, and therefore undergoing greatest contraction. This contraction must inevitably cause crowding, crushing, and crumbling of those shells that are nearer the surface, just as a stretched sheet of rubber coated with a layer of stiff clay would do when allowed to contract.

Somewhere between the surface shells of compression and the deepest shells of greatest cooling and contraction there will be a shell in a state of equilibrium, which the authors call the zone of no contraction. This zone, which was originally quite at the surface of our globe, tends to sink lower and lower as the general refrigeration or isotherms of our planet proceed downwards. Were the shells of cooling and contraction of great tensile strength, such as the experimental sheet of rubber, already referred to, we can quite understand how any fluid in the earth's interior would tend to be squeezed out, but are met by two difficulties—(1) is there any fluid in the earth's interior? and (2) is the tensile strength of the contractile shells sufficient to have a squeezing power?

Three classes of views have been held as to the constitution of our

[1] C. Davison: "On the Distribution of Strain in the Earth's Crust resulting from Secular Cooling, etc." (Phil. Trans. R.S., 1887, vol. clxxviii); "Note on the Relation between the Size of a Planet and the Rate of Mountain Building on its Surface" (Phil. Mag., Nov., 1887); "On the Straining of the Earth resulting from Secular Cooling" (Phil. Mag., Feb., 1896); "On Secular Straining of the Earth" (Geol. Mag., May, 1889, Dec. III, Vol. VI, No. 299, p. 220). T. Mellard Reade: *The Origin of Mountain Ranges*, 1886. See also H. J. Johnston-Lavis: "The Extension of the Mellard Reade and C. Davison Theory of Secular Straining of the Earth to the explanation of the Deep Phenomena of Volcanic Action" (Geol. Mag., June, 1890, Dec. III, Vol. VII, pp. 246–9).

globe. Some hold that it is like an egg—a solid shell with a fluid interior; others maintain that by the increase of gravity as the centre is approached there is a solid nucleus which is potentially fluid were it not for this gravitational condensation, so that there would be a solid nucleus, a solid crust, and a stratum of liquid rock separating them. Finally, there is a third school who holds that the highly heated nucleus, although potentially fluid, is really solid in consequence of pressure or, more correctly, gravitational condensation.

No known rock that we are acquainted with gives the conception of having sufficient tensile strength to be capable of exerting any really contractile or squeezing power on fluid enclosed within it or surrounded by it. There will be a tendency as the inner shells contract to split by fissures. Such fissures would extend from within outwards, and would be top-shaped in section, with the edge extending up to the neutral zone of no contraction, and their lower limit at the inner surface of the lowest shell (Fig. 1, E, F). Such a fissure might be simultaneously filled by the fluid rock-paste beneath.

How this filling will take place requires consideration. As there is reason to disbelieve in any considerable constricting power of the inner cooling shells, and that even if such constricting power did exist it would be annulled by the development of fissures within its mass, it is evident one must look to other causes. The welling up into the fissure of the fluid rock, if we admit a fluid nucleus or a stratum or shell of such fluid, might be due to the settling down by gravitation of the cooled blocks[1] of crust limited by the fissures. If, on the contrary, we admit the immediate contact of the lowest cooling shell with a highly incandescent nucleus (P), solid by pressure, but potentially fluid when this pressure is removed, we can well see what would take place. As soon as the fissures and therefore fluid in the inner cooling shells begin to form, their location and their edges will represent a site of diminished pressure. The subjacent and neighbouring but potentially fluid rock will in consequence liquefy and expand and fill the fissure. As the fissure broadens and extends so will the expansion and liquefaction increase *pari passu*.

Liquid rock may thus reach up to the neutral zone of no contraction, but its extension further must be a matter of chance. It is evident that if the shells of compression were in every part homogeneous and coherent, then no upward-pointed fissure could be formed. In practice neither of these conditions is fulfilled. It is obvious that the crowding and crushing will be most complete in the shells of compression (Fig. 1, C) where these are carried on a continuous block of contraction (Fig. 1, A). I mean by a block a portion bounded by fissures formed in the contracting part of the earth-crust. Where the shells of contraction are fissured (E, F) there the crowding of the superincumbent masses of cooled rock will not take place. As a result, each block or island of contractile crust, with its compressed burden, will tend to tear away from the adjoining blocks or islands, so that the limiting fissures in the contractile joints will extend up into the compressional shells (G, H).

[1] These blocks are quite different to the blocks referred to by some recent writers on terrestrial mechanics.

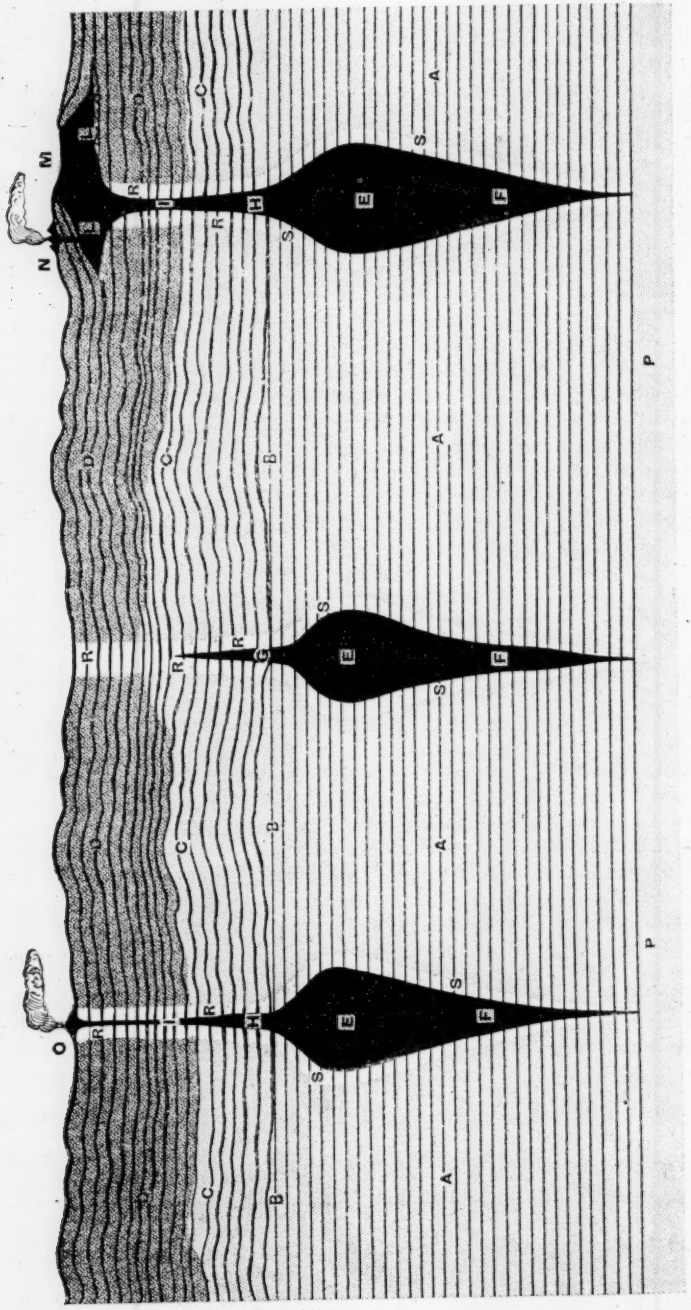


FIG. 1. Diagram showing the theoretical shells of contraction, compression, and fissuring on the earth's crust by process of cooling. Proportions greatly exaggerated. (For explanation see p. 443.)

This exactly fits in with what is frequently found in the distribution of volcanoes along the edges of areas of marked compression or mountain regions. It will explain also the presence of volcanoes having a linear arrangement between closely situated mountain chains or areas, as in South America. Great rifts, such as those of Central Africa and some cañon districts, are probably of such origin. In earthquakes of tectonic origin it has been pointed out[1] that the piers of damaged bridges have usually been found to have approached each other. This would evidently take place in the areas of positive compression (Fig. 1, C, C). On the other hand, in exceptional cases the piers have been found to have been separated. This might well occur in the area of negative compression (R), or what might well be termed the *areas of retraction*. The much larger proportion of the former effect on the bridge piers would no doubt be in the much greater ratio of compressional areas to retractional areas on the earth's surface.

May not ocean basins be in part due to blocks or islands of the contracting zones exerting that diminution of volume in a vertical more than in a horizontal direction, as we have so far been considering it to be? The peculiar abysmal ocean troughs often at the edge of ocean basins and parallel to chains of volcanoes or interrupted by them could well be explained by the same circumstances. I do not claim that ocean basins are alone due to this cause, but to a combination of these conditions with perhaps the slipping, shearing, and corrugating of the primitive crust over a fluid envelope, and even the tetrahedral collapse of a cooling globe. I lay down here but a general principle to which there may be many exceptions due to the vicissitudes of cooling and the variation in the materials concerned in any particular region, not to speak of the changing position of the earth's axis, the crustal inertia of Professor G. H. Darwin, etc.

Liquid rock having thus reached a considerable way to the surface, either as simple dykes (Fig. 1, I, I), laccolytes, or sills (Fig. 1, L, L), and so forth, is now in a situation suitable for the second series of phenomena, constituting what I call surface volcanic action, to come into play.

Surface Volcanic Phenomena.—Two schools of vulcanologists have held opposed views as to the origin of the volatile constituents contained in fluid igneous rock. One class of writers maintain that the gaseous contents are primordial, and have been contained in the igneous paste from the time that our globe condensed from the nebulous state. Others attribute all the volatile matter still retained in cooled igneous rock or evolved at volcanic mouths and fumaroles to the volatilization of water met by the igneous rock in its journey towards the surface. Probably both are right, but I propose to bring before you a series of my observations that point incontrovertibly to the fact that by far the major part of the volatile constituents of a magma are acquired by it on its journey towards the surface.

As condensation took place in our planet from a nebulous state, as each layer or shell of rock materials passed from the gaseous to the

[1] Professor Hobbs, Ninth International Congress of Geography, 1908.

liquid state, and probably solid, it is evident that those most volatile would be the last to change their physical state. That some of the more volatile ones were entangled or held in solution by the less volatile is quite likely, but the amount must have been small.

Another possible source of volatile matter in the deep-seated igneous matter may well be due to a slow osmosis or diffusion extending over vast periods of time and directed by the varying affinities of one class of matter for the other.

A quarter of a century ago, as a result of a careful and detailed study of Vesuvius[1] and other volcanoes, I was able to show that a volcano the more continuously active it was in the emission of igneous material the more tranquil was the character of emission, and that practically under such conditions lava was the only product. I showed also that the longer were the intermissions in the extrusive efforts of a volcano the more the ejecta tended to issue in a broken up and fragmentary condition, from the larger and more violent evolution of volatile or gaseous materials. We thus had the whole gamut of products—scoria, pumiceous scoria, scoriaceous pumice, pumice, and pumice dust—bearing a distinct ratio to the time that any volcano had been in a condition of 'repose'.

Two explanations offered themselves to my mind for this state of things. One was that the persistent evolution of volatile materials primordially stored up in the original volcanic paste escaping continually therefrom had collected in the volcanic chimney and blew out the magma; the other that the volatile materials were acquired by the igneous magma where in contact with water-bearing rocks in the upper strata of the earth's crust.

Were the former the case one would expect that the first products of an eruption should be less gas-filled or gas-bearing than the latter, but this is not the case. My observations, which demonstrate the fundamental facts upon which eruptive action of a volcano depends, show unmistakably that the first materials yielded in a normal eruption after a long period of 'repose' of a volcano are the richest in volatile elements, and that as the eruption proceeds the amount of gases in the issuing magma steadily diminishes, as shown by the diminished vesicularity and increased crystalline individualization of the essential ejecta.[2]

The class which interests us in the present question is the group of the *essential ejecta*. I found that when one examines the stratified deposits of the ejecta thrown out during an explosive eruption, that is, an eruption of great violence taking place after a long period of repose

[1] "The Geology of Monte Somma and Vesuvius": Q.J.G.S., 1884, vol. xl, pp. 35–119.

[2] In my paper "On the Fragmentary Ejecta of Volcanos" (Proc. Geol. Assoc., vol. ix, pp. 421–32 and 3 figs.) I divided such ejecta into three classes. *Essential ejecta* are those materials that issue in a fluid state, and consist either of the volatile constituents or the magma in which these were contained, that produced the particular emission in question. *Accessory ejecta* consist of the older volcanic materials of the same vent torn away, expelled, and mixed with the essential ejecta of an eruption. *Accidental ejecta* consist of either volcanic materials from other centres, or sedimentary or other rocks of the sub-volcanic platform, also torn out, expelled, and mixed with the two before-mentioned ejecta.

of an old volcano, or the initial outburst of a new one, the materials, as they fell from the air, show a definite arrangement, and vary in character in correspondence with different phases of the eruption.

To illustrate what these characters are I propose to choose a classical example in that of the great outburst of Vesuvius that overwhelmed Pompeii, Herculaneum, Stabia, Oplontis, and other towns around the foot of Somma-Vesuvius. If we examine the deposit of materials that fell during the eruption of A.D. 79 in the streets of Pompeii, or preferably outside the town as the falling houses have disturbed the regularity of the stratification within the walls, we find it made up of several beds. Immediately reposing on the old land surface is a stratum of very white light pumice. I use the word 'white' in comparison with that above it. If we collect a quantity of this we shall see that its bulk is very great for its weight. To the naked eye it is composed for the most part of a glassy vesicular base, with here and there scattered crystals of felspars, hornblende, pyroxene, and biotite, besides occasionally extraneous minerals caught up in the magma. Microscopically it is made up of a network of straw-coloured glass, with innumerable minute micro-crystals of leucite, all of a remarkably uniform size, besides which are a very few scattered microliths of hornblende, augite, mica, and felspars, obviously pre-eruptive in birth (Pl. XXV, Figs. 5 and 6). At wide intervals, of course, occur the porphyritic crystals above named. The main mass, however, is made up of glass, so that all the vesicles have been able to assume well-rounded outlines. The size of the vesicular spaces is very great in proportion to the amount of solid material enclosing them, making the pumice a very light one in weight.

Reposing on the bottom stratum, and rather suddenly graduating up from it, is the main bulk of the ejecta. The pumice composing this is much heavier, darker in colour, ranging from a brownish grey to a greenish grey. The porphyritic enclosed crystals are the same as those in the bottom, white pumice, and practically average the same size. They appear to be more frequent, but this is due to the pumice being denser; more of them are therefore to be seen in the same area, as it were more crowded together.

Microscopically this pumice very much differs from the subjacent white variety (Pl. XXV, Figs. 7 and 8). Nearly the whole of the glass has been replaced by innumerable microliths. The small leucites have increased but little in size, though they seem more numerous. This I attribute to the less amount of open space left by the vesicles. The augite microliths constitute the main bulk, and minute grains of magnetite are abundant. Some small microliths are probably distinguishable as felspars. Generally the vesicular cavities are much smaller. The vesicle walls are no longer smooth, but rough from the projecting microliths that in the process of rapid cooling grew and projected in all directions, and are not arranged with such parallelism that is seen in flow-structure with rods already in existence at an earlier date.

Both these divisions of *essential ejecta* are more or less mixed with *accessory* and *accidental ejecta* torn from the sides of the crater and the sub-volcanic platform. I mention this as it has a bearing on the composition of the third and uppermost part of the materials shot

out during an *explosive* eruption. This third or uppermost portion consists of a coarse or fine dust (ash), and when examined microscopically is seen to be to a large extent composed of detached microliths and loose crystals mixed with a large quantity of *pulverized accessory* and *accidental ejecta*. Whenever one examines the ejecta of explosive eruptions the same order is found. The above-mentioned characters are better seen in the case of very fluid intermediate or basic magmas, and I have given figures of the ejecta of an earlier explosive eruption of Somma-Vesuvius, Phase III, which is free from leucite (Pl. XXIV, Figs. 1–4).

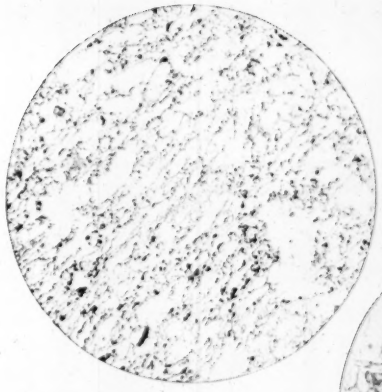
When eruptions are of a less violent explosive character the first part may be pumice and later a more compact and micro- and partially crystalline rock may issue, such, for instance, as the black pumiceous trachytic scoria ejected by the last efforts of Monte Nuovo, the main mass of the cone having been built up of a light buffish-white trachytic pumice.

In still less marked explosive eruptions, or where a large amount of material is ejected extending over some time, the final product may issue as a continuous mass and constitute a lava.

What, then, is the interpretation of this regular succession of ejecta having different characters? We know that the surface rocks of the earth's crust are as a body usually very aquiferous, and that as one descends the rocks become drier and drier. All the water has been squeezed out by superincumbent pressure. Of course, we know that according to the nature and composition of the rocks the depth to which aquiferous material extends will be extremely variable.

Let us figure to ourselves what would take place in a mass of fused silicates and oxides filling a fissure extending up through non-aquiferous into more and more aquiferous rocks. The prolonged contact would result in the *gradual solution* of the H_2O of the aquiferous strata in the fused paste, just as carbonic acid would be dissolved under pressure, but at ordinary temperature, in water. In the former case the critical point of H_2O does not come into the question. We know little of the temperature and pressure that this compound can exist at when dissolved in silicates and oxides. Furthermore, even if dissociated probably its components could pass into solution and re-combine again when temperature was lowered sufficiently. A careful study of volcanic action leads me to believe this process to be a slow one, so that if a fairly regular flow of melted rock takes place up the fissure through the aquiferous strata little H_2O is absorbed, and igneous outflow shows little violence, so that lavas are the chief products.

If the volcanic canal has never reached the surface, or is cut off from it by an old plug of solidified ejecta, then as the igneous magma acquires more and more H_2O its tension will steadily rise. Its loss of heat energy will be very little, as the H_2O and other volatile matters it has dissolved occupy a small volume. Still, in certain cases the magma may, as the result of different sources of heat loss, undergo complete cooling and consolidation. Not unlikely many hydrated rocks owe their origin to this cause. All evidence points to the heat energy or specific heat of basic rocks being lower in relation to their



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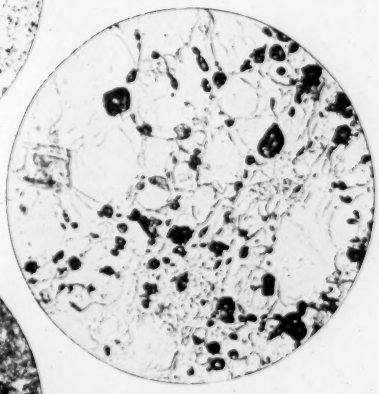
Phase III, Monte Somma, showing vast difference between the pumice ejected at the commencement and middle of an explosive eruption.



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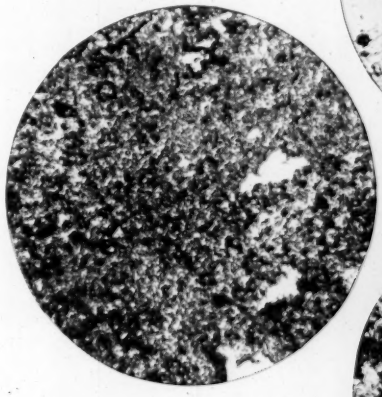

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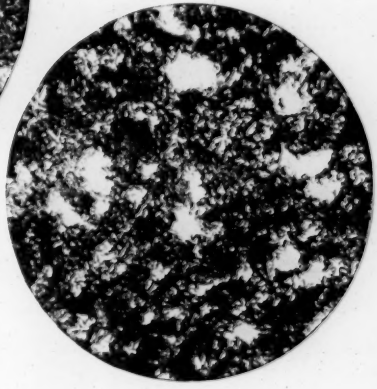

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Dr. H. J. Johnston-Lavis, micrographed.

Pumices and Pumiceous Scoria from explosive eruptions, Monte Somma and Vesuvius.

fluidity, which would explain in part why hydrated rocks are more frequent amongst them than are acid ones, as more frequently they would be cooled to consolidation before they found issue at the surface.

In many cases, however, the tension of the magma will steadily rise as it acquires more and more volatile matter from the surrounding rocks.[1] A moment will be reached when the tension has gradually attained such intensity that the earth's crust is rent by an extension upwards of the fissure. This fissure may reach the surface and make a new volcano, or the obstructing plug of an old one may be cleared away. In either case an explosive eruption will result.

Now the first portion to issue will be that part of the magma at the top of the fissure that has been in contact for the longest time with the more aquiferous rocks, and consequently will be richer in acquired volatile materials than that below. It may be a pure glass, or a certain number of crystals may have individualized under the intratelluric conditions of slow cooling. Once free from compression H_2O, etc., will separate from the non-volatile silicates and oxides as bubbles, undergo enormous expansion, escape in great part, and afford the explosive agent in the ejection of the remaining fluid-froth still holding much gas in the vesicles. This sudden expansion means a tremendous loss of heat energy, and the vitreous matter is so rapidly cooled that it has no time to individualize into microliths or crystals, or the crystals already existing to grow in size.

We know from the effect of pumice on combustible substances, as wood, bread, cloth, etc., as at Pompeii, that nearly all the latent heat has been used up in this expansion, so that only partial roasting has resulted. Thus has been produced the first white light pumice of an explosive eruption by the extremely rapid expansion and cooling of a pure or nearly pure glass.

As the upper contents of the volcanic canal blows out, that part of the magma lower down follows. This next portion has been a shorter time probably in contact with aquiferous rocks; these latter, being deeper, are usually poorer in H_2O. The consequence is that this second batch of magma will contain less volatile matter, expansion will be slower, there will be less loss of heat required for expansion, so that there will be time and other more favourable conditions for part of the glass to individualize into microliths. (Compare 1, 2, 5, 6, with 3, 4, 7, 8, Plates XXIV and XXV.) This second batch of magma furthermore will have lost less heat energy in consequence of having had less H_2O to dissolve, but also being deeply seated and in hotter rocks it will have lost less heat by conduction.

As we go deeper in the volcanic conduit these same differences will be exaggerated, so that as the magma escapes almost all the glass may be converted into microliths so as to leave little material to hold them together, whilst the evolution of volatile gases will be sufficient

[1] I use H_2O not to assume any special physical state of that substance. I also refer to it specially as being the principal volatile material of igneous magma; but I fully appreciate the salts and gases derived from their decomposition, as likewise the rarer materials that were acquired by and can be separated from igneous rocks by a high temperature, to which Monsieur Brun and others have furnished us with such interesting details by their studies.

to separate them into dust, producing the pulverized material constituting the essential part of the last and topmost deposit of an explosive eruption.

If the igneous paste rises from still greater depths it may come from little or non-aquiferous parts of the conduit, which, together with a higher specific heat from fewer losses thereof, will allow it to gush forth in a non-fragmented state as a lava.

The want of uniformity in the water-bearing rocks at different depths is too well recognized for us not to see the influence on possible departures and irregularities which might result in the sequence of ejecta having the characters I have shown you as the simplest expression of an eruptive phase.

In an open chimney of a volcano in chronic activity the constant circulation up the volcanic conduit allows of too little time for the magma to acquire much volatile materials, and it is only when this outflow is more or less impeded at the vent that more volatile materials are acquired and the volcano assumes paroxysmal or explosive fits.

In conclusion, I may say I have tried to summarize the trend of my researches for the last thirty years, and if you will try to read the whole phases of volcanic activity in this light *you will find it the only satisfactory explanation universally applicable to all cases of the eruptive mechanism.* No other theory that has been advanced has ever been based on the characters of the actual *essential ejecta*, and no other one fits without exception the whole range of the very varied phenomena of volcanicity.

EXPLANATION OF PLATES XXIV AND XXV.

Pumices and pumiceous scoria from explosive eruptions of Monte Somma and Vesuvius (*essential ejecta*).

Plate XXIV.

Fig. 1. Light white pumice, bottom part of Phase III, period 1. The section is seen to be mostly composed of a clear glass with only an occasional porphyritic crystal or microlith. Magnified 11 diameters.

,, 2. Part of the same section, magnified 50 diameters. Most of the vesicles are sectionized and open, and support the very rare porphyritic crystal by sections of the thin shells of glass. A few vesicles still contain air.

,, 3. Heavy chocolate-brown pumiceous scoria produced later by the same eruption, Phase III. Notice how much smaller are the vesiculæ and how the mass of rock material is principally composed of microliths. Magnified 11 diameters.

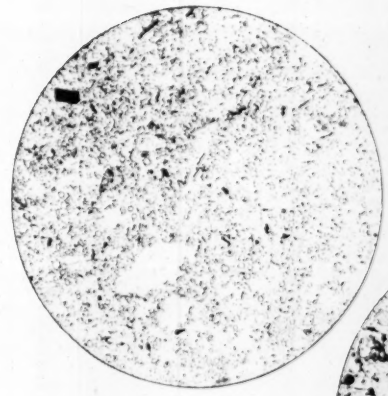
,, 4. The same, magnified 50 diameters. Here the numerous large smooth-walled vesicles of Fig. 2 are replaced by few small rough-walled spaces into which the microliths project.

Plate XXV.

,, 5. Light white pumice, bottom part of Plinian pumice that buried Pompeii. Phase VII, period 1. The section shows the material to be mostly a clear glass crowded by microliths of leucite only with few exceptions. Magnified 11 diameters.

,, 6. Part of same section, magnified 50 diameters, showing these characters more accentuated.

,, 7. Heavy greenish-grey pumice from high up in the pumice stratum. Here the rock is composed of a dark, almost opaque network of microlithic matter in which magnetite is abundantly distributed. The microliths are almost hidden by the opacity of the magnetite and augite grains. Magnified 11 diameters.



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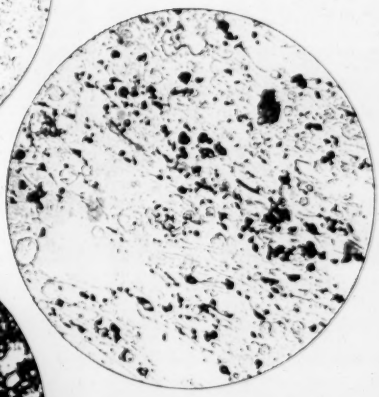
Phase VII, period 1, Pompeii eruption of A.D. 79, to illustrate same difference as last Plate.



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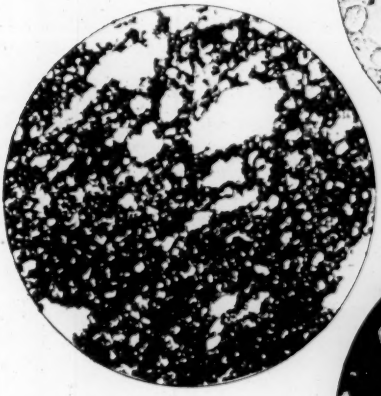

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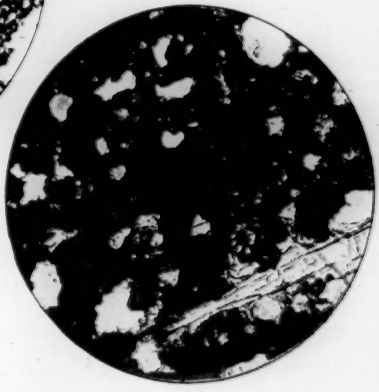

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Pumices and Pumiceous Scoria from explosive eruptions, Monte Somma and Vesuvius.

FIG. 8. The thinnest possible section to make is shown in this figure, magnified 75 diameters, exhibiting the extensive individualization of the glass into opaque microliths. The leucite microliths are represented by spots of imperfectly transmitted light where the crystal grains reach both sides of the slice, but are partially overlapped by augite and magnetite all around.[2]

DIAGRAM, p. 436.

A Shells of contraction.
B Neutral zone or zone of neither contraction nor compression.
C Dry shells of compression.
D Aquiferous shells of compression.
E Fissure between shells of maximum cooling and contraction filled by liquefaction of the edges of these shells by diminished pressure.
F Same, but in the shells of less cooling and contraction.
G Fissure extending up between two areas of compression and islands of contraction, but not reaching the aquiferous shells.
H The same, but reaching into the aquiferous rocks.
I The same, but having reached aquiferous shells has been enabled to extend upwards by explosive action into a laccolite and sill in one case and directly to a volcano in the other.
L Laccolite and sill exposed by erosion at M.
N Volcano supplied from uncooled part of laccolite, aquiferous rocks, and from rift I.
O Volcano supplied from rift I and aquiferous rocks around top of same.
P Portion of globe undergoing practically no cooling.
R Area of ineffective compression or retraction and depression.
S Area of ineffective contraction and of low pressure.

II.—NOTE ON TWO CEPHALOPODS COLLECTED BY DR. A. P. YOUNG, F.G.S., ON THE TARNTALER KÖPFE, IN TYROL.[2]

By G. C. CRICK, Assoc.R.S.M., F.G.S., British Museum (Natural History).

(PLATE XXVI.)

THE two Cephalopods—an Ammonoid and a Belemnoid—referred to in the present note were obtained in the summer of 1907 by Dr. A. P. Young from the Tarntaler Köpfe, an isolated mountain-mass in Tyrol, to the north of the Tuxer Alps, and about 20 kilometres south-east of Innsbruck. The Ammonoid was found "at a height of nearly 2500 metres above sea-level, on the surface of a scree-cone which has accumulated under the high hanging valley known as the Lower Tarntal", and the Belemnoid was found "somewhat lower on the slope of the same cone". They are the fossils referred to by Dr. A. P. Young on p. 342 of his paper on the Structure and Physiography of the Tarntal Mass, published in the August number of this Magazine (pp. 339–346), where a photograph of the scree-cone is given (Pl. XVII, Fig. 5), and now form part of the National Collection.

The Ammonoid[3] and its impression are displayed on the weathered surfaces of two plates of grey limestone that were found within 2 feet of one another. Since the impression does not supplement the details exhibited by the fossil itself, no mention is made of it in the following description. The specimen (Pl. XXVI, Fig. 1) has been not only crushed, but so greatly distorted during fossilization that its

[1] Had this specimen been chosen from the top of the essential ejecta of Phase III the thinnest section capable of being cut would have been opaque. It was taken, therefore, from a transition stratum (see p. 440).

[2] Published by permission of the Trustees of the British Museum.

[3] British Museum (Natural History), register number C. 12113.

form is now elliptical, the longer and transverse diameters being about 130 and 82 mm. respectively; the ellipse is obliquely truncated at one end by a natural fracture. Portions of only two whorls, the outer and the penultimate, are preserved; only a little more than one-half of the outer whorl is present, but the greater part of the penultimate whorl is more or less imperfectly preserved; the innermost whorls are not shown. At the anterior end of the specimen, that is, near one end of the longer diameter, the height of the whorl is about 33 mm., and the width of the umbilicus about 100 mm.; whilst at a quarter of a whorl back, that is to say, near the end of the transverse diameter, the height of the whorl is only 23 mm., and the width of the umbilicus 41 mm. The whorls were evidently comparatively narrow, and very evolute, with apparently scarcely any inclusion. The ornaments consist of simple, nearly straight, forwardly-inclined, and not very widely-spaced ribs, but it is difficult to estimate the exact width of the interspaces, or even the exact width (or height) of the whorls, because, owing to the distortion which has taken place during fossilization, the whorls are relatively narrower, and the ribs further apart near the extremities of the transverse diameter than they are near the extremities of the longer diameter. The ribs are nearly straight on the sides of the whorl, but turn somewhat abruptly forward almost close to, though without crossing, what is now the margin of the specimen. Although rather prominent, the bend of the rib does not appear to have been raised into a distinct tubercle. Unfortunately the fossil is so crushed that the form of the periphery cannot be seen. The margin just referred to, however, does not appear to have been at the centre of the peripheral area, but rather to have been the ridge bordering that area on one side, and separated from a median keel by a more or less distinct longitudinal groove. Near the earliest part of the outer whorl that is preserved there appear to be traces of three or four suture-lines, so that it would seem that the greater part of the outer whorl now present formed part of the body-chamber; no suture-lines are visible on the penultimate whorl. Naturally the suture-lines have participated in the general distortion of the specimen, and are now very obscure; they do not appear, however, to have been ceratitic.

The condition of the specimen renders any identification extremely difficult. The form of the peripheral margin and the general character of the suture-line, so far as it can be made out, seem to remove it from such genera as *Ceratites* and its allies, whilst these characters, together with the nature of the ribbing, suggest its reference to the Arietidæ. The fossil bears a striking resemblance to a figure given by Parona[1] of a specimen from the Lower Lias (*C. Bucklandi*-zone) of Alpe Loggio sopra Ponna (Vall' Intelvi), Lombardy, that he refers with a query to Dumortier's species *Arnouldi*,[2] a species included

[1] C. F. Parona, "Contribuzione alla conoscenza delle Ammoniti liasiche di Lombardia," pt. iii, Ammoniti del calcare nero di Moltrasio, Careno, Civate nel Bacino lariano (Mém. Soc. Pal. Suisse, vol. xxv, 1898), p. 11, pl. xv, fig. 5 (*Arietites* (*Arniocerας*) *Arnouldi*).

[2] E. Dumortier, *Études paléontologiques sur les dépôts jurassiques du Bassin du Rhône*, pt. ii, 1867, p. 27, pl. v, figs. 1, 2; pl. vi, figs. 1–6.

by Hyatt in his genus *Arnioceras*.[1] If the affinities of the specimen are really, as they appear to be, with that genus, the fossil seems to belong to the Lower Lias, though not to the lowest part of the Lower Lias, that is to say, that it is not of Hettangian, but rather of early Sinemurian age.

The Belemnoid (Pl. XXVI, Fig. 2)[2] is displayed in section upon the uneven weathered surface of a small piece of grey limestone, which, however, appears to be rather more dense than the matrix of the Ammonite just described. The specimen is 53 mm. long, being truncated posteriorly by the edge of the small piece of limestone on which it is exposed. The anterior half of the fossil is occupied by the alveolus. The guard as exposed is about 6·5 mm. wide, and therefore appears to have been comparatively slender; its sides are almost parallel; its posterior portion appears to be a little inflated, but this may be due to the fact that the exposed surface is uneven, so that the section which is exhibited does not lie in one plane. The angle of the alveolus as shown is about 16°, but as the plane of section may not be median, and may even be oblique, this angle may not represent, but be somewhat greater than, the real angle of the phragmocone. No portion of the phragmocone is preserved. The substance of the guard consists of a blackish, crystalline, imperfectly laminated material, the laminæ being a little oblique, both from side to side as well as from back to front of the specimen; these are sometimes accompanied by thin films of whitish calcite, but the guard does not exhibit indications, either of a radiate structure, or of concentric rings, or of a central axial line. No portion of the surface of the fossil is shown, but, judging from the transverse section of the truncated posterior portion of the guard, this appears to have been smooth. The specimen is clearly referable to the Belemnitidæ. The sub-family Aulacoceratinæ includes the four genera *Aulacoceras*, *Asteroconites*, *Dictyoconites*, and *Atractites*, in all of which, except the last-mentioned, the guard is variously ornamented; in *Atractites* it is smooth. If, therefore, our conclusion as to the nature of the surface of the guard is correct, the specimen, if referable to this sub-family, can only belong to *Atractites*. But the angle of the alveolar cavity, and the widening out of the portion of the guard around the alveolus, lead to the inference that the fossil does not belong to the genus *Atractites*.

Notwithstanding the present condition of the structure of the guard, the fossil appears to be referable to a subdivision of the genus *Belemnites*. The species is, however, quite indeterminable, though it may be stated that the guard was evidently much more slender than in such a form as Miller's *Belemnites acutus*.[3]

Notwithstanding their imperfect character these Cephalopods are of importance with reference to the alleged existence of Liassic rocks on the Tarntal mass. In 1859 Pichler[4] (p. 202) recorded the presence of

[1] A. Hyatt, *Genesis of the Arietidæ*, 1889, p. 162.

[2] British Museum (Natural History), register number C. 12114.

[3] J. S. Miller, Trans. Geol. Soc., ser. II, vol. ii, pt. i, 1826, p. 60, pl. viii, fig. 9.

[4] Adolf Pichler, "Beiträge zur Geognosie Tirols": Zeitschr. des Ferdinandeums für Tirol und Vorarlberg, 1859, Folge iii, Heft viii.

metamorphosed fossiliferous Lower Lias, and indicated the same on the map accompanying his work. The only Cephalopods mentioned, however, were Belemnites, stated to be easily distinguishable by their structure, though sometimes broken and their parts displaced.

Visiting the locality subsequently, Rothpletz[1] found there rocks containing Brachiopods, Lamellibranchs, and Corals, which he regarded as of Rhætic age, whilst in an overlying limestone, which Pichler considered to be of Lower Liassic age, he found only *Pentacrinus* ossicles, which, in his opinion, might belong to either Winkler's *Pentacrinus bavaricus* of the Kössener Schichten, or to the *Pentacrinus psilonoti* of Quenstedt from the Lower Lias. In reply to Rothpletz's inquiries Pichler stated that he could not remember the Belemnites, but only two Ammonites "(*radians!*)",[2] which he found in this grey limestone thirty-four years ago; also that he sent these specimens to the Geological Survey of Vienna, where, according to Rothpletz, they appear to be now unknown.

Although it is much to be regretted that the present specimens are very imperfectly preserved, it seems desirable to record them, since they serve to show the presence of a Cephalopod fauna on the Tarntaler Köpfe, and it is hoped that other examples may be obtained which will indicate the precise age of the beds yielding these fossils. It may be mentioned that the Ammonite found by Dr. Young differs entirely from Ammonites of the *radians* type.

It may be noted that on the highest part of the Kesselspitz (2722 metres above sea-level), some 16 kilometres west of the Tarntal mass, Professor Frech[3] records, above the Rhætic, the existence of Liassic beds containing indeterminable Belemnites, *Aulacoceras*, and Ammonites referable to the genera *Lytoceras*, *Arietites*, and *Phylloceras*. From the *Aulacoceras*, which he compared with *A. liassicum* (Gümbel), as figured by Mojsisovics[4] (p. 55, pl. iv, fig. 4*a*), together with an *Arietites*, he regards the fauna as Lower Liassic. The absence of *Psiloceras* and *Schlotheimia*, genera characteristic of the Hettangian, or lowest part of Lower Lias, is noted.

EXPLANATION OF PLATE XXVI.

Fig. 1. Weathered surface of slab of limestone, exhibiting an Ammonite (? *Arnioceras*); from the Tarntaler Köpfe, in Tyrol. Five-sixths nat. size.

Fig. 2. Weathered surface of a fragment of limestone showing Belemnite in section; from the same locality. Five-sixths nat. size.

Both specimens were collected by Dr. A. P. Young, F.G.S., who has presented them to the British Museum (Natural History).

[1] A. Rothpletz, *Ein geologischer Querschnitt durch die Ost-Alpen*, etc., 1894, pp. 74, 75, and 83.

[2] The trivial name *radians* has been applied by different authors to various Toarcian and Bajocian species of Ammonites. For synopsis of these species see S. S. Buckman, Mon. Inf. Ool. Amm. (Pal. Soc.), pt. iv, 1890, pp. 188–90.

[3] F. Frech, "Gebirgsbau der Tiroler Zentralalpen mit besonderer Rücksicht auf dem Brenner": Wissenschaftliche Ergänzungshefte zur Zeitschrift des D. u. Ö. Alpenvereins, Bd. ii, Heft i, 1905, pp. 1–98.

[4] E. v. Mojsisovics, "Ueber das Belemnitiden-Geschlecht *Aulacoceras*, Fr. v. Hauer": Jahrb. d. k. k. geol. Reichsanst., Wien, Bd. xxi, 1871, pp. 41–58, pls. i–iv.

Cephalopods from the Tarntaler Köpfe, in Tyrol.

III.—*Spirorbis*-Limestones in the 'Permian' of the South Staffordshire and Warwickshire Coal-fields.[1]

By T. C. Cantrill, B.Sc. Lond., F.G.S.

South Staffordshire.

A PERIOD of nearly forty years has now elapsed since several bands of *Spirorbis*-limestone were met with in the so-called Lower Permian rocks of the South Staffordshire Coal-field during the sinking of the Sandwell Park and Hamstead pits in the neighbourhood of West Bromwich. From the published accounts of those sinkings, in the first case by Mr. Henry Johnson, and in the second by Messrs. Meachem and Insley and Dr. Robert Kidston, *Spirorbis*-limestones appear to have been found at 206 feet above the base of the 'Permian' at Sandwell, and at 329 and 795 feet respectively at Hamstead.

But although the group of red marls and sandstones sunk through in the pits occupies a considerable area in the Clent Hills district, a few miles to the south-west, no surface outcrops of any such limestones had been discovered. It was particularly desirable, therefore, that an examination should be made of the sections of these red rocks afforded by the pipe-trench of the Birmingham Waterworks (Elan Supply), with a view to finding the surface positions of the bands of limestone met with in the pits, and of any others that might be present.

During the month of August, 1901, I was commissioned by the Director of the Geological Survey to examine the sections along the pipe-trench between the gathering ground at Rhayader, in Radnorshire, and the terminal reservoir at Frankley, near Birmingham. Several new facts were brought to light, and the more important of the results were recorded in brief in the *Summary of Progress* of the Geological Survey for 1901.[2] The following additional particulars of the discovery then made of outcrops of *Spirorbis*-limestone in the 'Permian' ground bordering the southern end of the South Staffordshire Coal-field may prove not uninteresting to those who have been watching the effect of recent investigations on the systematic status of the 'Permian' of Salopian type.

The pipe-track enters the 'Permian' at the village of Hagley, 3 miles south of Stourbridge, and continues wholly in those rocks as far as the terminal reservoir at Frankley, 5 miles farther east (see sketch-map, Fig. 1). These 'Permian' beds overlie the Coal-measures conformably, so far as is known, and are themselves covered unconformably by the Bunter Pebble Beds. They are well displayed in numerous brook-sections, and the highest member, the well-known 'trappoid' breccia, rises on the Clent and Walton Hills to a height of over 1000 feet above sea-level.

Mr. W. Wickham King[3] gives the Clent Hills sequence substantially as follows:—

[1] Communicated by permission of the Director of the Geological Survey.
[2] Mem. Geol. Surv., 1902, pp. 60–4.
[3] Quart. Journ. Geol. Soc., vol. lv, 1899, p. 97. See p. 111.

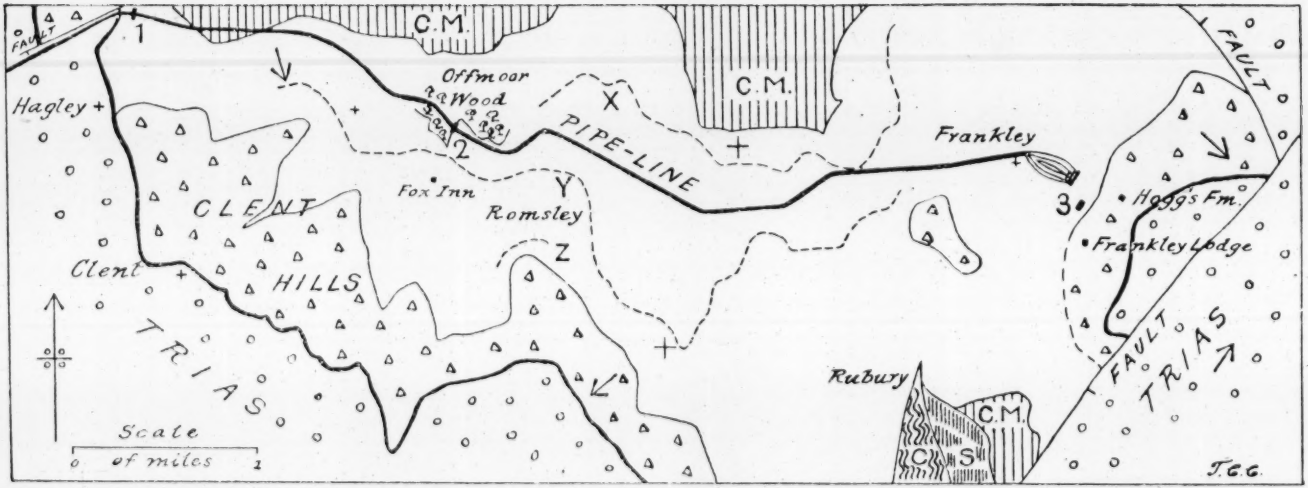

FIG. 1. Sketch-map (based on the Geological Survey map, Sheet 54 N.W.) showing course of pipe-line across the 'Permian' beds between Hagley and Frankley. Outcrops of *Spirorbis*-limestone are marked 1, 2, and 3. The Coal-measures (C.M.) crop out on the north, and again at Rubury on the south-east, where they overlie Silurian (S.) and Cambrian (C.) rocks. The Triassic rocks are marked by circles, and their base is shown by a heavy line. The trappoid breccia is shown by triangles. The unshaded portion of the map shows the outcrop of the Middle and Lower subdivisions of the local 'Permian', with outcrops of cornstone (X, Y, and Z).

			Feet.
Salopian 'Lower Permian'	Upper (C)	Trappoid breccia	450
	Middle (B)	6. Marls, and one thin band of sandstone . 50	295
		5. Cornstone 10	
		4. Marls, and 3 to 4 feet of brown sandstone 100	
		3. Cornstone 10	
		2. Marls 100	
		1. Cornstone and calcareous red sandstones . 25	
	Lower (A)	Sandstones and marls, say	200

With the trappoid breccia (C) we have no concern here. The so-called cornstones of the Middle division (B) appear to be calcareous sandstones containing small, rather angular chips and pebbles of pyroclastic rocks, with occasional pebbles of limestone.

The Lower Sandstones and Marls (A), which I correlated in 1895 with the fossiliferous beds of Sandwell, Hamstead, and Wyre Forest,[1] and claimed as Coal-measures, have since been identified by my colleague Dr. Walcot Gibson[2] with the Keele Beds of the North Staffordshire Coal-measures. The beds consist of red and crimson marls, mottled blue, with some pale-red sandstones and occasional bands of conglomeratic cornstone; some of the sandstones and marls are characterized by small green decoloration spots or 'fish-eyes'.

Hagley.—The pipe-trench entered these Keele Beds about 250 yards west of Wassel Grove Lane at Hagley.[3] At a point 100 yards west of the lane the debris from the trench contained small pieces of grey limestone, which, though they did not yield the characteristic Annelid, were clearly pieces of *Spirorbis*-limestone, derived doubtless from an outcrop close by (Fig. 1, 1). This band apparently lies not more than 50 feet above the base of the Keele Beds, the lowest members of which form a slight escarpment, about 300 yards to the north-east, easily to be recognized where it crosses the Birmingham Road immediately west of the Gipsy's Tent Inn. Obviously, then, this band of limestone is a new one, and will not do for any of those found at Sandwell, Hamstead, or in the Wyre Forest district: it is much too low in the sequence.

Romsley.—The same crimson marls with red sandstones apparently extend in an easterly direction through Hagley Wood and Offmoor Wood, and were open to view at several points on the pipe-trench, which gradually crosses the outcrop and slowly ascends the sequence. Just where the pipe-line emerges from Offmoor Wood, at a point 500 yards N.N.E. of the Fox Inn at Romsley (Fig. 1, 2), the debris again contained small pieces of limestone, though here also the fossil was not forthcoming. The horizon at which this outcrop occurs is probably at least 250 or 300 feet above the base of the Keele Beds, and to judge by the 1 inch geological map it is certainly considerably higher than any horizon so far reached by the trench, and I think there is little doubt that it lies well within the Middle subdivision (B).

Between Horsepool Farm and the Halesowen Railway the trench seems to have entered on a paler-coloured group of beds, containing some greenish-grey sandstone and conglomeratic cornstone. The tip

[1] Quart. Journ. Geol. Soc., vol. li, 1895, p. 528.
[2] Ibid., vol. lvii, 1901, p. 251.
[3] Old Series 1 inch map, 54 N.W.; 6 inch, Worcestershire, 9 N.E.

at Long Kettle's Wood, Frankley Green, consists of red marls, some being 'fish-eyed', with red and pale-grey sandstones. Red marls were exposed at the end of the pipe-trench 100 yards north-east of Frankley Church.

Frankley.—Here the bottom of the terminal reservoir, which lies in the valley of Merritt Brook, between the church and Hogg's Farm,[1] was being excavated to a depth of 12 feet, in red marls, with green mottlings, containing beds of soft red sandstone, the bedding being nearly horizontal. At the site of the filter-beds (Fig. 1, 3), which are situated a short distance west of Hogg's Farm, there occurred, among the marl and sandstone debris, numerous small pieces of limestone which after much search yielded a single specimen of *Spirorbis pusillus*, together with a few Ostracods.

As it was important to ascertain the exact source of these limestone pieces, I communicated with Mr. Fred. W. Macaulay, the engineer in charge, and from information he was good enough to supply it appears that the limestone outcrop was met with at some excavations for the filter-beds on the south side of Merritt Brook, at about 250 yards N. 20° W. of Frankley Lodge Farm. The limestone bed was found practically on the surface at the south side of the excavations, but dropped below the bottom of the excavations (10 feet below the surface) some 120 feet north of the outcrop. Allowing for a slight fall of the surface in the direction of the brook, this means that the limestone has a northerly dip of 5° or 6°. The bed was found to vary in thickness from 1 foot to 1 ft. 6 in.; the stone was rather rotten and friable. Mr. Macaulay had previously noticed pieces of the rock lying in an adjacent hedge, and evidently dug up from the field during draining or ploughing operations. Here, then, we have a third outcrop of *Spirorbis*-limestone in the 'Permian'-beds.

Now it will be observed, on an inspection of the Geological Survey map (54 N.W.) and the accompanying sketch-map (Fig. 1), that the three points at which the limestones crop out lie on successively higher horizons. Indeed, the Frankley Lodge outcrop, judging by the Survey map, is only a few feet below the base of the trappoid breccia, i.e. only a few feet below the top of the Middle subdivision (B). This, it is true, assumes the breccia to be conformable to the beds below, but I am not aware that any evidence to the contrary has been produced. According to the Horizontal Section, sheet 50, which passes through Frankley Lodge Farm, the base of the breccia is 450 feet above the base of the Keele Beds. But whether the breccia is conformable or not to the beds below, there seems no escape from the conclusion that the Frankley Lodge outcrop is high up in the Middle subdivision (B), and that the pipe-trench has proved three distinct limestone bands in the local 'Permian'. Hence it follows that not only the Lower subdivision (A), but the Middle subdivision (B) as well, must be correlated with the Keele Beds of North Staffordshire and relegated to the Coal-measures.

The three limestones appear to lie respectively about 50, 250, and 450 feet up in the 'Permian'. Those proved at the Sandwell and

[1] Six inch map, Worcestershire, 10 N.W.

Hamstead pits are 206, 329, and 795 feet above that horizon. It is therefore not possible at present to identify any of the outcrops with the bands passed through in the pits.

Warwickshire.

During the years 1902–5 occasional visits to the neighbourhood of Nether Whitacre, between Birmingham and Nuneaton, and a brief sojourn near Maxstoke, a few miles farther south, gave me the opportunity of looking for outcrops of *Spirorbis*-limestone in the 'Permian' rocks of the Warwickshire Coal-field. A *Spirorbis* band has long been known to occur in the ordinary Coal-measures at 150 feet below the base of the 'Permian', and its outcrop was laid down and described by Mr. H. H. Howell in the Geological Survey maps and memoir fifty years ago.[1] Mr. C. Fox Strangways,[2] too, in his recent revision of the Baxterley district, obtained evidence of a second band in the ordinary Coal-measures of that locality. But although the Warwickshire 'Permian' rocks have hitherto not been known to contain such limestones, as long ago as 1895 I made bold to claim them as Coal-measures, on the grounds that from all the available descriptions there was every reason to regard them as the equivalents of the Salopian Permian of the Wyre Forest district,[3] wherein I had recently found a *Spirorbis*-limestone and a thin coal-seam between 200 and 300 feet above the base of the group. Moreover, I find that Mr. William Andrews, F.G.S., of Coventry, in 1890 published the opinion that the Warwickshire 'Permian' are red Coal-measures, basing his conclusions apparently on the grounds of their lithological resemblance to the beds proved at Hamstead Colliery.[4]

Nether Whitacre.—But a passage in the Survey memoir on the coal-field shows that over fifty years ago Mr. Howell himself actually noticed a *Spirorbis*-limestone in the 'Permian' rocks, though its abnormal position with regard to the only known band (i.e. the one 150 feet down in the ordinary Coal-measures) misled him and prevented his realizing the significance of his discovery. After describing the outcrop of the band in the Coal-measures, Mr. Howell says (pp. 28, 29)—

"There can be little doubt that the limestone exists under the Permian rocks between Arley Wood and Sybil Hill near Kingsbury, although it is impossible to point out its precise position beneath that formation. There are, however, some indications of its having been wrought at Whitacre Hall, about halfway between Arley and Kingsbury. It was certainly burnt there, for the old kilns remain, and fragments of the limestone partially burnt are seen lying about the fields, but whether it was brought from Arley Wood, or Kingsbury Wood, or quarried on the spot, could not be ascertained, the works having been long abandoned. It is quite possible that the limestone may have been quarried here, exposed by the denudation of the Permian rocks."

[1] Sheets 62 S.E. and 63 S.W.; also *The Geology of the Warwickshire Coal-field*, 1859, pp. 26–9.

[2] *Geology of the Country between Atherstone and Charnwood Forest* (Mem. Geol. Surv.), 1900, p. 20.

[3] Quart. Journ. Geol. Soc., vol. li, 1895, p. 528. See p. 547.

[4] See a paper entitled "On the Bore-holes at Coventry", read before the Warwickshire Naturalists' and Archæologists' Field Club, March 26, 1890. (The reprints are issued without the particulars necessary for more exact citation.)

From an examination of the map I had always failed to see how the Arley Wood limestone, in the absence of serious faulting, could reappear at Whitacre Hall (three-quarters of a mile north-east of Nether Whitacre), and had come to the conclusion that what Mr. Howell had seen was in reality a limestone in the 'Permian', and not the Arley Wood band at all. This surmise I was able to confirm by an examination of the ground near Whitacre Hall in August, 1902.

At about 250 yards south of the Hall, in the south-eastern corner of a pasture-field adjacent to the public road, there are several old marl-pits, 8 or 10 feet deep, partly filled with water and bordered by dwarf oaks and thorns. In these pits, which were evidently excavated in crimson marls, were several pieces of dark-grey bituminous limestone, ranging in length up to 10 inches, and 5 or 6 inches thick. After producing nearly a barrowful of road-stone I succeeded in obtaining two specimens of *Spirorbis pusillus*. Whether the pits were dug for the purpose of extracting the limestone or for the sake of the red marl, there is little doubt that the limestone crops there. I saw no traces of the old kilns seen by Mr. Howell. To the north-east small pieces of limestone are to be seen on the surface of the farm-road leading eastward up the hill from the Hall; a large mass was noticed in the bottom of a grass-grown excavation close to this road and 600 yards east of the Hall; others, still farther east, were found in old pits near a barn by the side of the Hurley road. All these occurrences taken together suggest an outcrop running north-eastward toward Bull Barn, and although it would be impossible to lay down any definite line for it without further field-work, I have not the slightest doubt that we have here a band of *Spirorbis*-limestone which at a very moderate estimate of dip must be quite 150 to 200 feet above the base of the 'Permian'. There is no question, in my judgment, that the outcrop occurs, not in the ordinary grey and yellow Coal-measures exposed by denudation, but in the typical 'Permian' beds which are to be seen in quarries and other sections in the immediate vicinity.

Maxstoke.—Five miles south of Whitacre Hall another outcrop of limestone emerges among the 'Permian' marls immediately east of the boundary fault at a point three-quarters of a mile south of Maxstoke. A reference to the Geological Survey map (62 S.E.) shows the western margin of the 'Permian' to be a westerly down-throw which, ranging southward through Nether Whitacre, Maxstoke, and Meriden, throws down the Keuper Marl (f^6) on the west against the 'Permian' on the east, while a narrow strip of Lower Keuper Sandstone (f^5) emerges from beneath the Marl at Maxstoke and persists southward. Three-quarters of a mile south of Maxstoke a brook, rising at a strong spring at the foot of the wooded escarpment of Quarry Wood and Daniel's Wood (see Fig. 2), flows under the Maxstoke–Meriden Road, and passes a few yards north of the Hermitage Farm, on its way to join the Blythe. In the road, a few yards south of the brook, a shallow cutting shows about 4 feet of sandstone, chiefly soft and fine-grained, though some of the rock is calcareous and hard and contains small red and yellow fragments of marl. The bedding appears to be horizontal. Proceeding eastward, up-stream, sandy soil, blocks of sandstone, and one or two outcrops bring us nearly as far

as the first fence on the south. All the beds so far appear to be referable to the Lower Keuper Sandstone, as indicated on the Survey map.

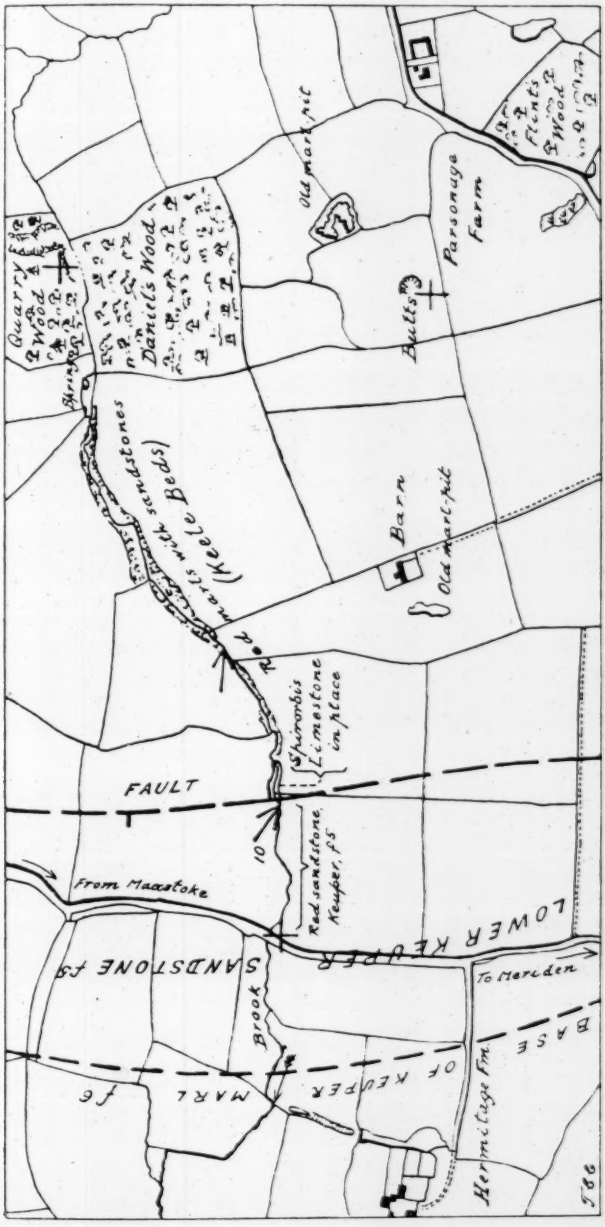

FIG. 2. Sketch-map, on scale of 6 inches to 1 mile, showing *Spirorbis*-limestone outcrop in Keele Beds near Maxstoke, Warwickshire. The base of the Keuper Marl is taken from the Geological Survey map, Sheet 62 S.E.

About 30 yards above this hedge, however, numerous small pieces of limestone suddenly appear in the stream. The rock is dark grey, bituminous, and fine-grained, and yielded a few Ostracods, but no *Spirorbis*. At 40 yards above the hedge (and about 260 yards from the road) the limestone appears in place, embedded in red marls of the usual bright-red 'Permian' tints. On the north side of the channel it projects at intervals for a distance of 3 or 4 yards; on the south also it can be detected; it is about 6 inches thick, and weathers into detached blocks not more than a foot across. The bed appears to be horizontal, and crops out in the banks of the channel at a height of about a foot above the water. The outcrop probably forms a small inlier immediately east of the fault, which presumably separates these 'Permian' beds from the Keuper Sandstones exposed down-stream and in the road-cutting. The actual fault-line is not visible, but I should draw it at the first fence, where the sandy soil on the west gives place to marly soil on the east. The supposed Keuper is to be distinguished from the 'Permian' only by the absence of bright-red and other marls; the sandstones themselves seem much alike. (Incidentally, the Survey map shows the fault some 300 yards too far to the east.) Still farther up-stream the exposures are chiefly of bright-red marls with subordinate sandstones, till the escarpment of Quarry Wood is reached and introduces a more sandy group of beds which have been quarried there and in a quarry (later used as rifle-butts) west of Parsonage Farm.

Here, then, we have a limestone which, though it did not yield *Spirorbis*, contains Entomostraca, and will probably be found to contain the characteristic Annelid also. It is lithologically similar to the limestones found in the so-called 'Permian' rocks of Wyre Forest and in the Keele Beds of North Staffordshire. Its position in the local 'Permian' sequence can at present only be guessed at. The Warwickshire 'Permian', as described in the Survey memoir and maps, seems capable of the following rough grouping:—

	Feet.
3. Red marls with sandstones	700
2. Calcareous sandstones, with the Corley conglomerate near the base . .	300
1. Red and brown sandstones and marls, with some calcareous conglomerates	1000

A study of the Survey maps leads me to believe that the Hermitage Brook limestone must be placed near the top of No. 1, and that it is certainly as much as 600 feet above the base of the local 'Permian'. It follows, therefore, that this subdivision (No. 1) at least can be correlated with the Keele Beds of the North Staffordshire Coal-measures, and I am now still more disposed than I was in 1895 to refer the whole of the Warwickshire 'Permian' to the Coal-measures, and to regard them as the equivalents of Dr. Gibson's Keele Beds, till such time as any part of the series can be shown to be true Permian or Trias.

In conclusion, it is to be hoped that during any sinkings through these Keele Beds now proceeding or in contemplation, a sharp look-out will be kept for *Spirorbis* and Entomostracan limestones, as well as for thin coals and plant-remains, as they will undoubtedly form a most useful guide in estimating depths to the productive measures below.

IV.—The Old Granites of the Transvaal and of South and Central Africa, by Cuthbert Baring Horwood, A.R.S.M., Assoc. M. Inst. C.E., F.G.S., with a Petrographical Description of the Orange Grove Occurrence, by Arthur Wade, B.Sc. (Lond.), A.R.C.S., F.G.S.

Introduction.

JUST over three years ago I described[1] the field relations, chemical composition, and petrographical characteristics of the Old, and also of the Newer, Red Granite of the Transvaal. As then, so now, I cannot do better than introduce this subject with the words of the late Charles Darwin[2]—"Granite to the geologist is classic ground; from its widespread limits, and its beautiful and compact texture, few rocks have been more anciently recognized. Granite has given rise, perhaps, to more discussion concerning its origin than any other formation. We generally see it constituting the fundamental rock; and, however formed, we know it is the deepest layer in the crust of this globe to which man has penetrated". South and Central Africa furnish no exception. Their granites, which are of astonishingly widespread occurrence, of varying and often characteristic texture, have been classic ground to geologists, as the numerous papers concerning them and their mode of origin and relative geological age well testify.

In this paper, which is divided into two parts, I propose in the first portion to give a few general notes on and to describe the Old Granites of the Transvaal and South and Central Africa; to review and summarize the knowledge which has gradually accumulated during the last decade concerning these Old Granites and associated gneisses, and from this, together with my own work in the field, to draw certain conclusions and deductions, the chief one being that in South and Central Africa there exists a fundamental or primary granite-gneiss formation, which has not up to the present been generally recognized.

In the second portion Mr. Arthur Wade, from a study of my slides, has given a very detailed petrographical description of the Old Granite occurring at Orange Grove, on the southern edge of the Johannesburg–Pretoria granite boss, about 3 miles north-east of Johannesburg. He has also added notes on its position in the New Quantitive Classification lately proposed and adopted by eminent American petrologists. Although this occurrence is not the most typical, yet it is sufficiently so, and we have selected it as being that which is best known in the Transvaal on account of its proximity to the Rand.

We had hoped to compare the chemical composition and petrographical features of these Old Granites with those of the old grey soda granite which forms the nucleus of the Cordilleras of the Andes of South America, but we were unable to find any record of an analysis or any petrographical description of this latter rock.

Part I. Description of the Old Granites.

The Old Granites are of a dull-grey colour, and are frequently characterized by the presence of porphyritic felspars, which are often

[1] *The Witwatersrand and Associated Beds*, by C. B. Horwood, June, 1905 (Esson & Perkins, Johannesburg), pp. 64–84.

[2] *Journal of Researches*, by Charles Darwin (Ward, Lock, & Co.), p. 276.

corroded; pink varieties also occasionally occur, as, for example, near the Yokeskey River on the farms Rietfontein (15) and Driefontein (461)[1] in the central portion of the Johannesburg–Pretoria boss; also in the Vredefort granite massif and in some localities of the Vryheid district; Dr. Voit[2] mentions a red variety in German South-West Africa, and I have found red and pink varieties in the Gordonia division of Cape Colony near the borders of German South-West Africa. Mr. H. Kynaston[3] mentions the occurrence of a coarse pink variety with large porphyritic felspars near the Swaziland border in the Komati Poort neighbourhood; also pegmatite veins of a pale-pink colour are found in the Old Granites.[4]

The Orange Grove granite is a dark-grey rock, characterized by large porphyritic crystals of plagioclase and orthoclase felspar, frequently corroded, measuring up to about 1½ inches in length by about half an inch in width, by rounded, lustrous blebs of quartz a quarter of an inch or more in diameter, and by the abundant presence of small particles of a dark-green biotite scattered throughout the mass, sometimes occurring in the felspar, which imparts a distinctly dark shade to the rock as a whole.

Dr. G. A. F. Molengraaff in his Annual Report for the year 1898, as State Geologist to the late South African Republic, in describing the Old Granite of the Transvaal at the same time drew a vivid comparison between it and the much more recent Red Granite.

In the light of subsequent investigations some slight alterations must now be made in this description, but for the most part it holds as good to-day as it did then, and it is the best general description which has so far been published, and I therefore reproduce it in full, as follows:—

Old Granite.

"The Old Granite is invariably of a grey colour, seldom red.

"The Old Granite is on most places a biotite, or two-mica granite; less frequently an amphibole-biotite granite or a muscovite granite, and seldom an amphibole granite.

"The felspar in the Old Granite always consists in a great measure of plagioclase or microcline. Not

Red Granite.

"This granite is, as the name implies, usually of a red colour.

"The Red Granite is on most places an amphibole-biotite granite and seldom biotite granite. Up to the present muscovite has never been observed in the Red Granite.

"The felspar in the Red Granite is almost exclusively orthoclase.

[1] *The Witwatersrand and Associated Beds*, by C. B. Horwood, 1905 (Esson and Perkins, Johannesburg), p. 67.

[2] "A Contribution to the Geology of German South-West Africa," by F. W. Voit: Trans. Geol. Soc. S.A., 1904, vol. vii, pt. ii, p. 84.

[3] "The Geology of the Neighbourhood of Komati Poort," by H. Kynaston: Trans. Geol. Soc. S.A., 1906, vol. ix, p. 21.

[4] A pink graphic granite was encountered 50 feet from the surface in sinking a well near the south-west corner of Illovo Township, about 5 miles north of Johannesburg. I have examined this in section under the microscope and find it consists entirely of a beautiful intergrowth of quartz and of water-clear microcline. Presumably the occurrence is that of a pegmatite vein in the Old Granite.

infrequently the rock is plagioclase granite or microcline granite.

"Granophyric structure has not yet been observed in the Old Granite.

"Pegmatite veins are to be found almost everywhere in the Old Granite; and it not infrequently presents a reticulated appearance, caused by the ramifications of thick and thin dykes and veins of pegmatite throughout its mass. There is an abundance of handsome graphic granite to be found in the pegmatite.

"Syenite has not yet been found in the region of the Old Granite.

"Passages of the Old Granite to quartz-porphyry or related rocks are not known, but here and there dykes of quartz-porphyry do break through the Old Granite.

"Effusive rocks and volcanic ejectamenta which might be considered as belonging to the granite family are never found in the region of the Old Granite.

"In the Old Granite segregations of the basic components from the granite magma occur on a very small scale and play an unimportant rôle.

"On most places granophyric structure is beautifully developed in the Red Granite, and is very characteristic of this rock.

"Veins of pegmatite have not yet been found in the Red Granite.

"Syenite occurs very frequently with the Red Granite, and often that rock is entirely or partly changed to pistacite-syenite.

"In many instances the Red Granite passes gradually over into porphyritic forms belonging to the quartz-porphyry and felsite-porphyry group. Sometimes we find then true quartz-porphyry where quartz and felspar both occur as phenocrysts in a dense ground-mass, more frequently felsite-porphyry with large porphyritic crystals (phenocrysts) of red felspar as Carlsbad twins.

"In connection with the Red Granite, and at its base, resting on the underlying older rocks of the Pretoria Series (for instance, on Mr. Pretorius' farm, Roodeplaat, No. 314), distinctly stratified eruptive rocks, tufts, and breccias, with numerous slag inclusions occur, which certainly may be considered as volcanic ejectamenta of the granite family. They lie intercalated with sheets of felsite-porphyry, which represent old lava streams.

"In the Red Granite the dark, most basic components are here and there segregated and separated out from the magma in large aggregates. Foremost of these occur

accumulations of the amphibole, whereby local rocks originate which may be designated hornblende rocks. Of much more importance, however, is the segregation of the most basic materials —the iron ores from norite—at the base of the Red Granite, which have conduced to the origin of important ore masses consisting of chrom-iron and magnetite. The norite and gabbro themselves, of which, among others, the range known as the Zwartkoppies consists, may not improbably again be considered as basic segregations from the Red Granite magma on a large scale, but up to the present the data are insufficient to enable one to decide with certainty on the matter.

"In the Red Granite region schists have never yet been met with."

"The Old Granite is intimately connected with the schists. It not infrequently even possesses a more or less banded structure, and passing then over to gneissic or amphibolitic rocks; while in many places bands of schists are interbedded. In such cases the schists consist of amphibolite, especially actinolite schists, chlorite schist, sericitic schist, staurolite schist, andalusite schist, etc."

From a more recent work we now know that muscovite does occur in the Red Granite.[1] From a specimen of Red Granite which I obtained from Balmoral I have had a section cut which contains microcline; the occurrence of this mineral in the Red Granite is, however, extremely rare. Granophyric structure is sometimes present in the Old Granite.[2] Also passages of the Old Granite into quartz-diorite and quartz-porphyry sometimes occur, and Mr. H. Kynaston[3] has called attention to their occurrence in places along the southern margin of the Johannesburg–Pretoria boss.

In view of our present more advanced knowledge I would suggest the following comparison between the Old Granite and the Newer Red Granite:—

[1] *The Witwatersrand and Associated Beds*, by C. B. Horwood, 1905, pp. 68, 69.

[2] Loc. cit., pp. 65, 68; also *vide* "The Geology of the Neighbourhood of Komati Poort", by H. Kynaston: Trans. Geol. Soc. S.A., 1906, vol. ix, p. 21.

[3] "The Marginal Phenomena and Geological Relations of the Granite North of Johannesburg," by H. Kynaston: Trans. Geol. Soc. S.A., 1907, vol. x, pp. 56–8.

	Old Granites.	*New Granites.*
1. Origin.	Plutonic.	Volcanic (inasmuch as it represents the intra-liquid slowly-cooled portion of an enormous volcanic sheet).[1]
2. Age.	Primary or fundamental.	Later than the Pretoria Series, probably later than the Waterberg Series.[2]
3. Chief Macroscopical Characteristic.	Usually of a grey colour.	Red in colour.
4. Chief Microscopical Characteristic.	Very general presence of microcline.	Very general presence of granophyric structure.
5. Chief Field Characteristics.	Presence of quartz and pegmatite veins and diabase dykes. Marginal modifications; such as quartz-diorite, schists, and gneissic granite; association with amphibolite rocks, schists, and gneisses.	Association of three types— 1. Upper felsitic portion. 2. Hypidiomorphic granite, originally intermediately situated. 3. Panidiomorphic granite, originally centrally seated, or interior. Also presence of more basic rocks around its periphery, such as syenites, norites, gabbros, pyroxenites, etc.

Possibly some slight latitude must be allowed in this use of the term volcanic, to give greater antithesis to the above comparison of the two granites. It designates rocks which have consolidated at or near the surface,[3] and it is in this latter sense that it is here employed.

Dr. Molengraaff says:[4] "I consider the Red Granite, as forming a portion of an enormous sheet, although of a decidedly micro-pegmatitic structure, has much in common with that of the plutonic rocks, which is my justification for still retaining the name Granite.

[1] Geological Survey of the South African Republic, Annual Report for 1898, by Dr. G. A. F. Molengraaff, pp. 5, 6.

[2] Some of the Red Granite is certainly more recent than the Waterberg Series, *vide* "The Waterberg Sandstone Formation and its Relation to other Formations of the Transvaal", by E. T. Mellor (Trans. Geol. Soc. S.A., 1904, vol. vii, pt. i, p. 45); also "The Red Granite of Balmoral and its Relations to the Cobalt Lodes", by C. B. Horwood (Trans. Geol. Soc. S.A., 1904, vol. vii, pt. ii, p. 110).

[3] *British Petrography*, by J. J. Harris Teall, p. 451.

[4] Geol. Surv. of the S.A. Republic, Ann. Rep. for 1898, pp. 5, 6.

The apparent contradiction disappears if we take into consideration that we have here to deal with a stream of acid—probably very viscous—lava of enormous extent and thickness. This explains how the intra-liquid portion could cool only very slowly, and thus acquire the characteristic structure of plutonic rocks. We must assume that, after the decomposition of the Magaliesberg Beds in the area which is now the Bushveld, there followed a period of volcanic activity on a very large scale. . . . The bed of the Pienaars River on the farms Baviaanspoort (No. 470), Leeuwfontein (No. 320), Zeekoegat (No. 287), and Roodeplaat (No. 314) offers excellent opportunities for the study of the earlier results of the above-mentioned eruptive activity, followed by the outflow of a colossal stream of granite lava, which in its central and lower portions consolidated to a 'granite' with micropegmatitic structure, the portion nearer the surface, however, furnished rocks belonging to the quartz-porphyry and felsite-porphyry group." Later[1] he speaks of the intrusion of a magma, rich in soda, which might have been of the nature of a laccolite, intruded between the Waterberg and Pretoria Series. However, whether portion of an enormous sheet or of a laccolite, the origin of the granite, in either case, is the same.

This explanation of the origin of the Red Granite is not incompatible with modern ideas. Sir Archibald Geikie states[2] that granite may occur "connected with true volcanic rocks, and forming, perhaps, the lower portion of masses which flowed out at the surface as lavas. In the Tertiary volcanic region of the west of Scotland, masses of granite and granophyre have pierced the sheets of sub-aerial basalts, and must have risen near to, if they did not actually reach, the surface. They prove that granite is not necessarily, though usually an abysmal rock".

Returning now to the Old Granite, Mr. H. Kynaston[3] has described the granite at the old Half-way House between Pretoria and Johannesburg as a somewhat coarse rock of a pale pinkish-grey colour, with occasional large flesh-coloured felspars showing more conspicuously among the other constituents, and says that under the microscope it is seen to consist mainly of a somewhat coarse aggregate of microcline, plagioclase, and quartz, with a few small flakes of white mica. He states that the proportion of ferro-magnesian constituent is small, and consists of biotite, partially chloritized, and a very small quantity of green hornblende; also that apatite is accessory, and that a few small grains of epidote appear as a secondary constituent.

In this same granite boss, near the dynamite factory on the farm Modderfontein, I have found a reddish-grey granite, in which small particles of violet-coloured fluorspar were easily discernible in the hand specimen.

Dr. G. A. F. Molengraaff[4] has given such a very full and careful

[1] *Geology of the Transvaal*, 1904, pp. 57–60.

[2] *Text Book of Geology*, by Sir A. Geikie, 1903, vol. i, p. 208.

[3] "The Marginal Phenomena and Geological Relations of the Granite North of Johannesburg," by H. Kynaston: Trans. Geol. Soc. S.A., 1907, vol. x, p. 55.

[4] "Note on the Geology of a Portion of the Klerksdorp District, etc.," by Dr. G. A. F. Molengraaff: Trans. Geol. Soc. S.A., 1905, vol. viii, pp. 24, 25.

description of the Old Granite in the Klerksdorp District that I quote it in full—

"*Microcline Granite*:—Specimens from Haartebeestfontein (624), Oorbietjesfontein (201), and Rhenosterhoek (585). *Macroscopic*: a grey granite of medium grain. The lamellar twinned character of the triclinic feldspar is easily recognisable with a pocket lens.

"Under the microscope the rock shows a typical granitic hypidiomorphic structure. The primary constituents are microcline, plagioclase, orthoclase, quartz, muscovite, some iron ore, biotite, rutile, zircon, and tourmaline. The secondary constituents are chlorite and muscovite. Feldspar and quartz preponderate so much over the other minerals that the latter only occur in clusters here and there in the rock, or as enclosures in the quartz or feldspar. Iron ore is very sparingly represented by some crystals of magnetite and by some hydrated iron oxide, which may have been derived from hæmatite. Mica is chiefly represented by muscovite; part of the muscovite is altered into chlorite in such a way that each crystal of muscovite is altered into a chlorite crystal with the same crystallographic orientation. The chlorite is distinctly pleochroic and shows 'Höfe' with very strongly marked pleochroism, and those often contain in their centres minute grains of zircon.

"The muscovite enclosed in quartz is always quite undecomposed. Biotite occurs only in small quantities enclosed in quartz or in feldspar.

"Feldspar occurs chiefly as microcline, which forms, in fact, the bulk of the rock. With the exception of quartz, the microcline was the last mineral to crystallize in the rock, which is proved by the fact that numerous well-planed crystals of orthoclase — mostly Carlsbad twins—and also crystals of plagioclase are enveloped by microcline. The characteristic 'Gitterstructur' of the twinning is very fine. The microcline was found to be quite fresh and undecomposed in all the specimens, whereas both orthoclase and plagioclase was less pellucid and partly decomposed, numerous small flakes of secondary muscovite having been formed in them.

"Quartz fills the gaps left after the crystallization of all the other minerals, and also contains all these as enclosures; zircon, rutile, and tourmaline are found only as enclosures in the quartz. The rock shows signs of having been subjected to great pressure, which is revealed under the microscope by the undulatory extinction of the quartz, and by the numerous bends and cracks in the other minerals; this last phenomenon is, of course, most clearly shown in the lamellar plagioclase."

Dr. J. A. Leo Henderson,[1] referring to the Yokeskey River granite (in the Johannesburg–Pretoria massif), remarks that "a regular mutual intergrowth between biotite, muscovite, and green pleochroic chlorite was observed parallel to the cleavage traces, and it would appear that, as Molengraaff suggests, the chlorite has been derived from the primary biotite. A good deal of the muscovite is primary, containing tiny zircon inclusions, but much is secondarily derived from

[1] *Petrographical and Geological Investigations of certain Transvaal Norites, Gabbros, Pyroxenites, and other South African Rocks*, by Dr. J. A. Leo Henderson, 1899, p. 44, Dulau & Co., London.

the feldspar through decomposition. Broken needles of rutile in the quartz grains and contorted mica folia, as well as the bent and broken feldspars, combined with undulose extinction of the quartz and feldspars, indicate considerable cataclastic action. This probably explains, as Molengraaff observes, the cross-hatching structure of the microcline".

Dr. Voit,[1] speaking of the Old Granite of German South-West Africa, says that the frequent occurrence sometimes in veins and sometimes in great masses of pegmatite is characteristic. He states that mica occurs as large as a man's hand, and a red felspar (microcline) of gigantic size, like graphic granite, with quartz inclusions; that the mica is chiefly muscovite, accompanied sometimes by biotite in small flakes, sometimes, too, small flakes of a green mica occur in the graphic granite, in which the blow-pipe affords evidence of chromium; that tourmaline is a very common constituent of the granite, and occurs in both large and small individuals up to an arm's length and thickness; that clusters of small apatite crystals are often to be found in the red felspar; and that topazes and beryls are found as long as one's hand, the latter being of a completely opaque and dirty variety, the clear, bluish-green, glassy variety of aquamarine being seldom found. He also describes the gneiss-granite district as unusually rich in secondary minerals, the felspars near Ganab being frequently changed to zeolites.

Mr. A. W. Rogers,[2] Director of the Geological Survey of the Cape Colony, in describing the granite massif which stretches from St. Helena Bay to Klein Dassen Berg, a distance of about 70 miles, says that many varieties of granitic rock occur, the most abundant being, perhaps, a two-mica granite, with orthoclase as the chief felspar. He states that every gradation between a normal granite and a gneiss can be found, and that the massive granite is seen in the interior of the area and the foliated rock near the periphery, but that this rule has many exceptions. He says that large and small veins or dyke-like bodies of microgranite and quartz-porphyry, with a microgranite base, are found towards the edge of the area in many places; and tourmaline is often present in the rock near Darling. Also that in the hills to the south and west of Darling there are some remarkable rocks associated with the granite and gneiss; colourless augite, plagioclase, and sphene are added to the usual constituents of the granite, and mica is practically absent; the structure is that known as granulitic, the various minerals occurring in grains of a more uniform size than is the case with ordinary granite. These rocks often show a parallel structure, but have not the foliated or schistose planes seen in the gneiss. He adds that the nature and origin of the granulites of Darling are as yet unexplained, as is also their exact relationship to the surrounding granite and gneiss.

With regard to the Malmesbury granite boss, he says that it is mainly a rather coarse biotite granite with porphyritic orthoclase, but fine, grained granite, composed of the same minerals, and coarse pegmatites are not infrequent, and that there seems to be no gneiss.

[1] "A Contribution to the Geology of German South-West Africa," by Dr. F. W. Voit: Trans. Geol. Soc., vol. vii, pt. ii, pp. 84, 85.

[2] *The Geology of Cape Colony*, by A. W. Rogers, pp. 38–42.

Again, he describes the granite of Paarl Mountain as a biotite granite associated with dykes of quartz-porphyry but not with gneiss. Further, he remarks that "the granites of the Paarl and Stellenbosch districts contain a fair amount of microcline, a variety of felspar which is rare in the Saldanha Bay and Darling area, although it seems to be the chief felspathic constituent of the granites in the northern and north-western parts of the Colony. On the south-west edge of the Bottelary granite cassiterite or tin-stone occurs in a gneissose muscovite granite, together with tourmaline; wolframite has been found in the same neighbourhood".

In describing the smaller of the two granite masses near Somerset West, he says: "The main mass of the intrusion is a biotite granite with little muscovite, but the muscovite is very abundant in certain places and the felspar decreases in amount and may disappear completely, so that the rock becomes a greisen or quartz-muscovite rock. In other parts tourmaline is extremely abundant, sometimes giving rise to a schorl rock, composed of tourmaline and quartz only. At other places andalusite, showing a beautiful pink tint under the microscope, forms a large part of a rock composed of quartz, tourmaline, muscovite, andalusite, and apatite."

Professor E. Cohen,[1] of Greifswald, has recorded the presence of pinite (an alteration product of cordierite) in the biotite granite of Table Mountain. Mr. Rogers[2] describes the granite mass of George as containing both muscovite and biotite granites, with tourmaline and fluorspar; and associated with gneissose rocks.

With regard to the granite and gneiss of the Prieska district, he[3] observes that the foliation planes of the gneiss are in general parallel to the strike of the sedimentary rocks in its neighbourhood; he thinks it not unlikely that the intrusion and solidification of the granite and gneiss occupied a long period, and that we have in the gneiss the earlier, and consequently most altered, products of the acid magma; but he says that "whether any part of the granite is of much later date than the bulk of the intrusions is not yet settled. Some of the very fresh-looking granites on the farm Schalk's Puts might certainly be considered younger than the gneiss, but there are so many intermediate varieties that the evidence of a considerable difference in age between the extreme types must be clearly made out before that opinion can be accepted". He then proceeds—

"The chief constituents of the acid intrusions are quartz, orthoclase, microcline, albite, and an intergrowth of orthoclase or microcline, and a plagioclase felspar, black and white mica, the latter sometimes (e.g. Grenaat's Kop and Alicedale) in crystals up to 10 inches in width, but too frequently bent by the movements which the rock has undergone since its solidification; hornblende is not often met with; apatite and iron ores are not abundant; garnets occur, especially in certain gneisses, and in the rocks with the same

[1] "Geognostisch-petrographische Skizzen aus Süd Afrika:" Neues Jahrbuch für Min., etc., 1874, p. 460.

[2] *The Geology of Cape Colony*, by A. W. Rogers, p. 44.

[3] Loc. cit., pp. 79–83.

constituents as the granite but with granulitic structure. Tourmaline seems to be absent from the Prieska granites.

"Pegmatite or graphic granite, chiefly composed of an intergrowth of microcline and quartz, forms a large mass in the neighbourhood of Saft Sit Pan. Quartz-porphyries are rather restricted in their occurrence; they have been found only within the granite areas, and are not known to traverse the surrounding rocks in the manner of the quartz-porphyries near Paarl Berg.

"The granulites of Prieska are abundant and vary greatly in composition. They are fine-grained rocks, usually showing distinct banding on large weathered surfaces, but the banding is often unobservable on a freshly broken surface. They are usually dark in colour, but the more acid or siliceous types are light-coloured. In general appearance they look rather like even-grained quartzites. It is only under the microscope that the distinctive features of the granulites are seen. The most striking character is the uniformity in size of the grains of the various minerals composing the rocks; another important feature is the almost complete absence of crystalline faces in the minerals, which seem to have separated out in a different manner from that usual in igneous rocks; enclosures of one mineral by another are abundant, but the enclosed mineral is irregularly shaped, usually with a rounded outline. Garnet, which is an important constituent of most of the Prieska granulites, is the only mineral which sometimes shows crystal faces, and it very often contains small grains of more than one of the other minerals composing the rock. All the minerals in the granulites are remarkably fresh and free from alteration products. The rocks may be broadly divided into three groups—(1) Granulites made up of the same minerals as the granite and gneiss, viz., quartz, felspar (orthoclase and plagioclase), garnet, and biotite. This seems to be a less abundant rock than those belonging to the two other classes to be mentioned, but on account of its being rather closely related to much of the gneiss, into which it passes by the coming in of a pronounced foliation and the increase in size of some of the felspars, it is easy to overlook small outcrops in the gneiss areas. (2) Hornblende-granulites, composed of quartz, orthoclase, albite, hornblende, biotite, magnetite, garnet, and sphene. The hornblende is a pale, bluish-green variety, different from the hornblende of most of the hornblende schists. Garnet is a less abundant mineral constituent than in the next group. (3) Pyroxene-epidote-granulites, composed of plagioclase, augite, epidote, garnet, magnetite, sphene, and frequently hornblende. The pyroxene is a pale-green or bluish-green monoclinic variety, diopside, and is slightly pleochroic. The abundance of epidote, which often forms a large part of the rock, is very remarkable.

"The granulites form elongated outcrops in the granite and gneiss, with the longer axes of the areas parallel to the foliation planes of the gneiss; they have not been found as intrusions in the sedimentary rocks. The nature of their contact with the gneiss has not been made out, as the line of junction of the two rocks is almost invariably concealed under the red sandy soil that the granite and gneiss give rise to. The composition of the pyroxene-granulites must be very

different from that of any of the gneissose or schistose rocks yet found in Prieska, and it is therefore impossible to consider them as local modifications of any of the latter, as the biotite-granulites may be with regard to the gneiss. The amount of lime and alumina in the pyroxene-granulites must be greater than is usual in igneous rocks containing the same varieties of plagioclase. The granulites give one the impression of being intrusive, but the question of their origin is quite unsettled."

I have quoted Mr. Rogers' description of these rocks in full because he has given such a clear and detailed account of them, and because there can be no doubt that the granulites of the Prieska district are genetically connected with the normal type of granite, and Mr. Rogers is evidently inclined to admit a difference in age between them and the normal granite. Mr. Rogers[1] also mentions the occurrence of peculiar types of well-foliated gneiss amongst the Southern Bushmanland granites and gneisses at the base of the Langeberg in Calvinia, which consist chiefly of quartz, plagioclase, enstatite, hornblende, and biotite, and occur in bands enclosed in gneiss of more normal character. He further states that garnetiferous granite and gneiss are abundant in that area.

A description of certain microcline gneisses of the Congo Free State, which are petrographically remarkably similar to some of the gneisses already mentioned, will be found further on.

Review of Work done during the Last Decade.

Some of the work already done has of necessity been mentioned under the last heading, but that which has not yet been alluded to I now propose to review.

In 1897[2] Mr. A. R. Sawyer drew attention to what he called the Rooi Kopjes mass of granite, situated south of Heidelberg between the upper and lower Rooi Kopjes. The granite is here overlain unconformably by a small outlier of Karroo Beds, and does not outcrop at the surface, but has been encountered in bore-holes. According to Mr. Sawyer's description it occurs at a considerable depth below the level of the Witwatersrand rocks which outcrop around it, and dip away from it along the margin of the Karroo Beds, which here form the South Rand Coal-field. He stated "that the gneissoid granite, forming the base of this coal-field, is part of the basement underlying the whole of South Africa, and is here, in the writer's opinion, distinctly anterior to the banket formation".

Later,[3] in 1903, he states, in referring to his previous description of this occurrence, that it appeared to him at that time "that the gneissoid granite formed part of a protrusion of the vast underlying deep-seated granite foundation which I have seen in so many parts of South Africa, from the coast in Cape Colony to beyond Salisbury in Mashonaland, and which I believe underlies the whole of South Africa, and that it

[1] Loc. cit., p. 91.

[2] "The South Rand Coal-field and its Connection with the Witwatersrand Banket Formation," by A. R. Sawyer: Trans. Inst. M.E., 1897, vol. xiv, p. 312.

[3] "Remarks on some Granite Masses or the Transvaal," by A. R. Sawyer: Trans. Geol. Soc. S.A., 1903, vol. vi, pt. iii, pp. 47–9.

produced a large flexure or anticline, and was not therefore posterior to the uplifted rocks". Then in the same paper he says, "since then I have found out by boring that the dip of the Witwatersrand and Hospital Hill Beds is steeper near the granite," and he suggests that the steep dip of the rocks east and west of the granite points to the granite being intrusive in them.

Thus, in his opinion, the Old Granite is the basement rock on which the Witwatersrand Beds were laid down, and which subsequently invaded them by after-intrusions. It is also of interest to note that in 1897 [1] he mentioned an occurrence of granite containing veins of white quartz on the farms Varkenskraal and Klerkskraal, which are traversed by the Mooi River, 35 miles north of Potchefstroom, and stated that banket reefs (Black Reef Series) containing glassy white quartz pebbles can be seen resting on the granite on these farms, and that the white quartz veins of the granite "can be seen passing through various gradations of decomposition until they reach the final stage of banket pebbles".

Dr. Molengraaff, in his report for the year 1897, as State Geologist of the South African Republic, under the term South African Primary Formation with Intrusive Granite Bosses, includes—

1. Granite and schists.
2. Hospital Hill Series and Barberton Beds.
3. Witwatersrand Series.

And he states that the beds of this formation have been much altered, both by dynamo-metamorphism and by contact-metamorphism, in the vicinity of the granite bosses. Also, he speaks of numerous granite masses which are found intrusive in this formation. Later, in the same report, he speaks of the granite as intrusive in the bottom part of this formation.

In his report for the following year he classes the Witwatersrand Series (our present Witwatersrand Beds) as the upper division of the Barberton Series, and in his table of the sequence of the various formations he puts the Barberton Series as conformable with the Old Granite and schists, but puts a query mark against the sign for conformability.

In a paper [2] read by him in June, 1903, on the tectonics of the Vredefort district he shows in a most convincing manner how the overtilting of the beds is there due to the intrusion of the granite. The chief arguments which he brings forward in support of this contention are that at a certain distance from the great central granite boss small enclosures of granite are found entirely surrounded by rocks of the South African Primary System, being apparently offshoots of the main granite boss; also that unmistakable signs of strong contact-metamorphism are found in the lowest portion of the sedimentary strata around the granite, the strata nearest to granite being entirely crystalline, and having the character of crystalline schists, especially actinolite schist; and up to some distance from

[1] Loc. cit., p. 13.

[2] "Remarks on the Vredefort Mountain-Land," by G. A. F. Molengraaff: Trans. Geol. Soc. S.A., vol. vi, pt. ii, pp. 20–6.

the granite the shaly and slaty rocks are charged with contact minerals. Of these he describes two chief types—(*a*) apparently porphyritic, more or less schistose rocks, composed mainly of corundum and biotite in fairly large crystalline grains, all interlarded by a kind of network of quartz; in some varieties phenocrysts of corundum are very conspicuous on the surface of the rock, having been so left by reason of their strong resistance to weathering; (*b*) highly ferruginous and magnetic banded slates, being identical with the well-known Hospital Hill Slates, but for their being charged with spherulites or bunches of actinolite. And further, he points out that the steep dip and overtilting of the beds surrounding the granite boss is not due to one main axis of dislocation at right-angles to which lateral pressure was exerted, but the axis of overtilting gradually changes in direction all round the granite boss, keeping tangental to it, so that evidently the pressure has been exerted in every instance from its centre towards the periphery. Since all the series of beds from the granite up to and including the Pretoria Series has been more or less overtilted, and since sandstones of the Karroo formation near Vredefort rest in a perfectly horizontal and undisturbed position on the granite, the intrusion must have taken place after the deposition of the Pretoria Series and before the deposition of the rocks of the Karroo System. Dr. Hatch,[1] in discussing this paper, stated that he thought it extremely probable that Dr. Molengraaff was correct in his view with regard to the overtilting of the Witwatersrand Beds.

Although Dr. Molengraaff had treated this occurrence in such a masterly way, and his conclusions were based on such sound premises, yet because one occurrence of the Old Granite was afterwards shown to be non-intrusive in the Lower Witwatersrand Beds in the Heidelberg district,[2] instead of realizing that his previous work in the Vredefort district had proved that the Old Granite was intrusive in places, even if not so everywhere, and therefore did not all belong to one and the same period of intrusion, he in August, 1904, says:[3] "the recent studies of Messrs. Dörffel and Corstorphine have led me to doubt the correctness of my opinion that the Old Granite is intrusive in the Lower Witwatersrand Beds (Hospital Hill Series), and I consider this question open to revision in the case of the granite of the Vredefort boss also."

In his *Geology of the Transvaal* (1904) he states that the whole of the South African Primary System represents one single series, of which the rocks are greatly modified in their structure by contact-metamorphism produced by granitic intrusions. He then states that in the districts where the South African Primary System has been well developed, as in the Barberton district and in the Witwatersrand, it is preferable to distinguish a lower series confined to the vicinity of the old intrusive granite, consisting of crystalline schists, and an upper series composed of rocks of clastic origin. He adds a footnote

[1] Trans. Geol. Soc. S.A., vol. vi, pt. iii, p. 30.

[2] "The Geological Relation of the Old Granite to the Witwatersrand Series," by G. S. Corstorphine: Trans. Geol. Soc. S.A., vol. vii, pt. i, pp. 9–12.

[3] Trans. Geol. Soc. S.A., 1904, vol. vii, pt. ii, p. 115.

to the effect that recent investigations tend to prove that in the Southern Transvaal the Witwatersrand System was deposited on the pre-existing Old Granite, and that for the time being he considers the question whether this granite must be regarded as intrusive in the oldest sedimentary rocks as doubtful, and as direct proofs of the granite being intrusive in Hospital Hill Series are wanting he suggests that possibly the upper and lower series of the South African Primary System are of different ages, the majority of the crystalline schists being segregations and alterations by pressure from the granite. Thus at first he was of the opinion that the Old Granite was intrusive in the Hospital Hill Series (our present Lower Witwatersrand Beds), but later felt doubt about this and reserved a final opinion. Moreover, in discussing Mr. Jorissen's paper,[1] which I refer to later, he says,[2] in reference to the relation existing between the Witwatersrand Series, Swaziland Series, and the Old Granite, "Possibly the granite is intrusive into both of these; possibly also the granite in different places may belong to separate intrusions of different ages." The recent investigations which he referred to were started by the late Mr. D. Dörffel[3] in December, 1903. Until then the Old Granite was generally considered intrusive in the Witwatersrand System.

(*To be continued in our next Number.*)

V.—The Homotaxial Equivalents of the Culm of Western Germany.

By Dr. W. Hind, B.Sc. Lond., F.G.S., etc.

IN the Geological Magazine, 1904, Dec. V, Vol. I, p. 403, I criticized the view put forward by Dr. Parkinson that the Culm beds in the neighbourhood of Marburg were of Lower Carboniferous or Tournaisian age. Last summer I had the advantage of being taken over the ground by Professor Kayser, of Marburg, and also of seeing his valuable and extensive collections from the Culm of various parts of Germany.

The view that the Culm of Germany is of Lower Carboniferous age has naturally arisen from the fact that it certainly forms the base of the Carboniferous rocks of Western Germany, and that these rocks rest on Upper Devonian beds with *Clymenia* without any apparent great unconformity. Unfortunately sections showing anything like a complete sequence are unknown, and the Culm seems to have been laid down in several small basins over a gradually sinking area of Upper Devonian rocks, themselves much moved and interrupted by volcanic outbursts, so that the lowest bed or beds of the Culm are not everywhere present.

By comparing the zonal fossils of the known sequence of the Culm or Pendleside Series in either Great Britain or Belgium with

[1] "Notes on some Intrusive Granites in the Transvaal, the Orange River Colony, and in Swaziland," by E. Jorissen: Trans. Geol. Soc. S.A., vol. vii, pt. iii, pp. 151–60.

[2] Proc. Geol. Soc. S.A., to accompany vol. viii of the Transactions, 1905, p. 32.

[3] "Note on the Geological Position of the Basement Granite," by D. Dörffel: Trans. Geol. Soc. S.A., vol. vi, pt. v, pp. 104–5.

those of the various Culm beds of Western Germany, a very definite and normal succession of zonal sequence can be made out. The fauna of the Culm, as exhibited in the Museum of the Geological Department of the University of Marburg, is typically that of the Pendleside Series and Culm of Great Britain; all the important zonal Cephalopoda are present, and I consider in normal succession.

It is practically unthinkable that similar successions of Cephalopod forms could be evolved at two distinct periods of geological time, which the view of the Tournaisian age of the Culm of Western Germany would necessitate. It is known that in Belgium and Great Britain the Pendleside or Culm fauna is always post-Viséan, and consequently the presence of the typical fauna in Germany determines the age of the German Culm to be also post-Viséan.

In Great Britain the faunal sequence which succeeds the Viséan subdivision of the Carboniferous Limestone is as follows:—

Zone of *Gastrioceras Listeri*	Millstone Grit.
Zone of *Glyphioceras bilingue*	Millstone Grit.
Zone of *Gl. spirale* and *Gl. diadema*	Pendleside Series.
Zone of *Gl. reticulatum* (maximum)	
Zone of *Nomismoceras rotiforme* and *Posidonomya Becheri* .	
Zone of *Prolecanites compressus* in upper part of *Cyathaxonia*-zone.	

Glyphioceras crenistria is common in the upper part of the Viséan or *Dibunophyllum*-zone.

The majority of these zonal forms are found in Belgium in the same sequence, and the fauna which is found in the Pendleside Series and its equivalent in Belgium is a Lower Carboniferous fauna, but post-Viséan.

In Germany the Culm beds lie on a diabase of Upper Devonian age, intrusive into the *Clymenia* beds, a sequence practically identical with that which obtains in North Devon. The lowest Culm fauna is obtained from lenticular patches of limestone at Breitscheid, and German authorities are agreed that this is the case. The following fauna has been obtained at Breitscheid:—

Prolecanites compressus.	*Trincoceras hibernicum.*
Glyphioceras crenistria.	*Dimorphoceras Gilbertsoni.*
G. mutabile.	*Orthoceras scalare.*
Pericyclus virgatus.	*Orthoceras* cf. *salvum*, de Kon.
Brancoceras ornatissimum.	Corals.

This is a fauna which is distinctly characteristic of the highest Viséan or *Dibunophyllum* horizon of Great Britain and Ireland, and contains the type or zone fossil of the passage beds between the *Dibunophyllum*-zone and the Pendleside Series. I am informed that a similar fauna has been found at Erdbach and Liebstein, but the beds are very local and not persistent, and are often entirely absent.

The so-called 'Mittel Kulm' is much more fossiliferous, and perhaps the best exposure is at Herborn, the fauna of which has been described by v. Koenen ("Die Kulmfauna von Herborn": Neuen Jahrebuch für Min., Geol., u. Pal., 1879, p. 311). At Herborn the series consists of calcareous shales, the 'Posidonien Schiefer',

with small nodules, which rests on 7–8 metres of black chert; this, in turn, rests on a diabase of Upper Devonian age. The section is—

	Metres.
Grauwacke or grit	130–200
Posidonomya Becheri shales	20–25
Black chert	7–8
Upper Devonian diabase.	

The Herborn flora and fauna is typically that of the Lower Pendleside Series, with the exception that *Pterinopecten papyraceus* has not been found there. The fauna is rich, and the most important members are—

Adiantites antiquus.
Glyphioceras reticulatum.
G. diadema.
Nomismoceras rotiforme.
Orthoceras striolatum.
O. scalare, often called with us *O. Koninckı.*
Aviculopecten Losseni.
Posidoniella lævis.
Posidonomya Becheri.
Actinopteria persulcata.
Camaropteria papyracea.
Listracanthus Beyrichi.
Trilobites.

I regret to say that I did not visit the Culm of Westphalia, but thanks to Professor Kayser I was able to study his fine collection of fossils from that area, and with his information as to the sequence have arrived at the following results.

Professor Kayser's collections were from two localities — Hagen and Aprath, near Elberfeld. The general sequence is as follows :—

	Metres.
Flotzeere Sand-stein, with plants	2000
Culm Tonschiefer, with *Glyphioceras reticulatum*	200
Dark thin-bedded limestones, with Hagen fauna at base	200
Silicious limestone, with Goniatites	50
Cherts, with Aprath fauna	
Phtanites, with *Prolecanites compressus*	5
Devonian Rocks	

The Aprath fauna contains a fauna typical of the very lowest of the Pendleside Series—

Prolecanites compressus,
Nomismoceras rotiforme,
Trincoceras hibernicum,
Pleurodyctium Dechianum,
Productus plicatus, Sarres,

and, as might be expected, the oldest facies of any fauna in the sequence.

The fauna of Hagen also contains a number of late Viséan forms of Brachiopods, such as are found in and known to range throughout the Pendleside Series of England (Congleton Edge), together with Goniatites, which are known to be associated with *Posidonomya Becheri* in Devonshire.

Glyphioceras striatum.
G. sphæricum.
Glyphioceras crenistria.
Orthoceras Morrisianum.

At Scarlet, Isle of Man, and various localities in North Staffordshire, also near Cracoe in Yorkshire, and Black Hall near Chipping, these Goniatites abound in limestones immediately below the *Posidonomya Becheri* shales.

D. W. Wolterstorff has described the Culm of Magdeburg, and his figures of fossils show that the fauna is identical with that of Herborn. I suspect, however, that he has there also the fauna of a higher zone, for I think it probable that the Goniatite he figures as *Dimorphoceras Tornquisti* may be either *G. bilingue*, *G. Phillipsi*, or *G. reticulatum*.

The presence and persistence of the Pendleside or Culm fauna over Western Europe, and the fact that its zone fossils always succeed each other in normal sequence, affords most certain and definite evidence for the correlation of the Pendleside Series and the Culm of Devonshire with the Namurien of Belgium and the Culm of Germany, and that the view that the Culm beds of Germany are below the Viséan and are the homotaxial equivalents of the Tournaisian must, on palæontological grounds, be revised.

When discussing the question on the ground I found that the view that *Posidonomya Becheri* was a very unsatisfactory zonal form and that it occurred again and again at various horizons was strongly urged, and certain stratigraphical facts were also cited in support of the view that the German Culm-measures were of Tournaisian or ante-Viséan age.

In the first place it is known that *P. Becheri* occurs low down in the Yoredale Series of Wensleydale in black shale above the Hardraw Scar Limestone, but the associated fauna is a Viséan one and not a Pendleside or Culm fauna, and it may be said that *P. Becheri*, with the peculiar Cephalopods which constitute the Pendleside fauna, has a very narrow horizontal distribution indeed. But the case does not depend on this fossil at all. I rely absolutely on the Cephalopod succession and the fauna as a whole. It is most improbable that such highly organized forms as *Prolecanites compressus* or *Nomismoceras rotiforme*, with their peculiar sutures, genera which only existed for very brief periods as measured by vertical succession, should have characterized different series of rocks in the British–Belgian area and in Germany.

In 1904 (Geol. Mag., Dec. III, Vol. I, pp. 272–6) Dr. Parkinson, on palæontological grounds, definitely made out the Culm of South Germany to be below the horizon of the Viséan division of the Carboniferous Limestone. I was shown the stratigraphical evidence in the field by Professor Kayser, whom I beg to thank for his lucid explanations and for permission to study the whole of the palæontological material on which the views were based. In the neighbourhood of Königsberg, north of Giessen, are outcrops of a slaty breccia, with some limestones, which yield the following fauna :—

Productus giganteus.
P. punctatus.
P. semireticulatus.
Orthotetes crenistria.
Corals.
Cyathophyllum.
Cyathaxonia.
Spirifer cf. *bisulcatus.*
Chonetes papyraceus.
Cyclophyllum.

This is a fauna of a high Viséan phase, undoubtedly and totally distinct from any of the hitherto known Culm faunas of Germany. There is, however, no section which shows the relation of this fauna

to the Culm faunas. The Königsberg Beds are underlain by a grauwacke or grit, and the Herborn Beds or Posidonien Schiefer are overlain by a similar rock, and it is therefore surmised that this grauwacke represents a definite horizon and demonstrates the relation of the Viséan beds of Königsberg to the *Posidonomya* shales of Herborn. The whole district is much disturbed, faulted, and overthrusts are many and on a grand scale, the Königsberg Beds are themselves much contorted and broken, and the exposures very small, that sufficient detail of stratigraphy does not obtain.

Near Königsberg, 400 yards east of the village, is a small section which shows the following succession:—

Posidonien Schiefer.
Cherts.
Diabase.
Upper Devonian.

A succession similar to that which exists at Herborn. These beds are cut off by a fault and then the section shows grauwacke, on which lies the slaty breccia containing the Viséan fauna.

In the absence of detailed stratigraphical evidence of the relation of the Königsberg Beds, it is argued that the beds with Viséan fauna cannot be below the *Posidonomya* cherts, because there is no room for them between the Devonian diabase and the chert. But it is forgotten that the lowest Culm fauna, the Breitscheid or *Prolecanites compressus* fauna, which is admitted to be below the *Posidonomya* beds, is absent at Königsberg. And further, this argument begs the whole question, because it assumes that there was no interval or unconformity between the outburst of the Devonian diabase and the deposit of the Posidonien Schiefer.

The question is not one that demands much imagination, however. The Viséan fauna found at Königsberg is that which is always found to immediately precede the *Prolecanites compressus* beds and normally should be only a few feet below it, and it is not therefore at all strange to find evidences of both faunas in very close proximity, but it is important to recognize that the Culm of Western Germany is late Carboniferous, and not Tournaisian, and the appeal to palæontology pronounces a very definite and certain verdict on this point. The solution of the question was impossible in Germany, on account of the absence of sections and the disturbance, contemporaneous and afterwards, due to volcanic activity and earth-movements. It is of the greatest interest to find that the questions of the relation of the Upper Devonian to the Culm are practically identical in Germany and Devonshire, and to know that the oldest Carboniferous rocks in Germany are late Viséan.

Recent work in Belgium by Dr. Purves,[1] M. Cornet,[2] and M. Renevier afford additional evidence for the views advanced in the above paper.

[1] Bull. l'Acad. Roy. Belg., ser. III, pt. ii, No. xii.
[2] Am. Soc. Géol. Belg., t. xxxii, pp. 139–52.

NOTICES OF MEMOIRS.

I.—British Association for the Advancement of Science, Seventy-ninth Annual Meeting, held at Winnipeg, August 26–31, 1909. List of Titles of Papers read in Section C (Geology) and in other Sections bearing upon Geology.

Address by the President (*Dr. Arthur Smith Woodward, F.R.S., F.G.S.*).—The Evolution of Vertebrate Animals as shown by Fossils (see Geol. Mag., September, p. 413).

J. B. Tyrrell.—The Geology of Western Canada.

Professor A. P. Coleman, Ph.D.—The Extent of the Ice Sheets in the Great Plains.

Warren Upham, D.Sc.—The Glacial Lake Agassiz. (See p. 475.)

Professor E. F. Chandler.—The Rainfall Run-off Ratio in the Prairies of Central North America.

Professor A. P. Coleman, Ph.D.—The Bearing of Pre-Cambrian Geology on Uniformitarianism.

Professor W. G. Miller.—The Pre-Cambrian Rocks of Canada.

A. R. Dwerryhouse, D.Sc.—An Outline of the Glacial Geology of Britain, illustrative of the Work of the Committee on Erratic Blocks.

Dr. Aubrey Strahan, M.A., D.Sc., F.R.S.—The Glacial Geology of South Wales.

David Woolacott, D.Sc.—On the Classification of the Permian of the North of England.

Herbert Bolton.—New Faunal Horizons in the Bristol Coalfield.

Professor S. H. Reynolds, M.A.—Description of the Avon Section, Bristol, in illustration of Dr. A. Vaughan's work on the English Carboniferous Limestone.

Professor S. H. Reynolds, M.A.—Lithology of the Carboniferous Limestone of Burrington Combe, Somerset.

Ernest Dixon, B.Sc.—On some Structures in Limestone Formations.

Professor W. G. Miller.—Gold and Silver Ore-deposits of Canada.

Professor A. P. Coleman, Ph.D.—Copper and Nickel Deposits of Canada.

Professor W. G. Miller.—Iron Ore-deposits of Canada.

J. B. Tyrrell, M.A.—Placer Mining in Canada.

Professor T. L. Walker, Ph.D.—Rare Metals found in Canada.

Professor J. W. Gregory, D.Sc., F.R.S.—Report of the Committee on South African Strata.

Charles F. Juritz, M.A., D.Sc.—Topographical and Geological Terms in South Africa.

Report of the Committee on Topographical and Geological Terms in South Africa.

Tempest Anderson, M.D.—The Volcano of Metavanu.

Professor J. W. Gregory, D.Sc., F.R.S.—Exhibition of the Material described as Geyserite from the Mount Morgan Mine, Queensland.

A. Smith Woodward, LL.D., F.R.S.—Discovery of Dinosaurs in the Cretaceous of Australia.

A. Smith Woodward, LL.D., F.R.S.—Discovery of a Dinosaurian Tooth in the Trias of Brazil.

Professor S. H. Reynolds, M.A.—Certain Aspects of British Scenery as illustrating the work of the Geological Photographs Committee.

Henry C. Beasley.—Report on Footprints found in the Trias of Great Britain.

Professor S. H. Reynolds, M.A.—Report of the Committee on the Geology of Glensaul, co. Galway.

E. S. Cobbold.—On some Further Excavations among the Cambrian Rocks of Comley, Shropshire, 1908.

Report of the Committee on the Drift Deposits of Kirmington, Lincolnshire, and the East Riding of Yorkshire.

Report on the Crystalline Rocks of Anglesey.

Report on the Chemical Composition of Charnwood Rocks.

Report on the Salt Lakes of Biskra, Algeria.

List of Titles of papers read in other Sections bearing upon Geology:—

Section A.—Mathematical and Physical Science.

F. Napier Denison.—Effects of Atmospheric Pressure on the Earth's Surface.

Professor A. E. H. Love, F.R.S.—Discussion of "Earth Tides".

Section D.—Zoology.

E. S. Goodrich, F.R.S. (Oxford).—The Origin of Vertebrates.

Professor A. B. Macallum, F.R.S. (Toronto).—Palæobiology and the Age of the Earth.

J. Stanley Gardiner, F.R.S. (Cambridge).—Coral Reefs.

Section E.—Geography.

A. O. Wheeler.—Some Characteristics of the Canadian Rockies.

J. Stanley Gardiner, F.R.S.—The Seychelles.

Professor Hobbs (Michigan).—Cycle of Alpine Glaciation.

Miss L. A. Owen.—Floods in the Great Interior Valley of America.

Professor A. P. Coleman.—The Yellowhead Pass and Mount Robson.

Professor Dodge.—The Formation of Arroyos in Adobe-filled Valleys in the South-Western United States.

Professor D. W. Johnson.—The Development of Nantasket Beach near Boston.

M. Allorge.—The Eastern (Tunisian) Atlas Mountains; their Main Structural and Morphological Features.

Section G.—Engineering.

J. B. Porter.—An Outline of an Investigation now being conducted for the Dominion Government on the Coals of Canada.

Section H.—Anthropology.

Report of the Committee to investigate the Lake Villages at Glastonbury.

Report of the Committee to conduct explorations with the object of ascertaining the age of Stone Circles.

Report of the Committee to investigate Neolithic Sites in Northern Greece.

Report of the Committee to conduct Archæological Investigations in British East Africa.

Professor E. Guthrie Perry.—On a Recent Find of Copper Implements in Manitoba.

C. Hill-Tout.—Report on the Ethnology of the Okanagan.

Dr. G. B. Gordon.—Ethnological Researches in Alaska.

Professor H. Montgomery.—Archæology of Ontario and Manitoba.

SECTION K.—BOTANY.

J. Parkin.—The Evolution of Inflorescence.

Dr. Kidston, F.R.S., & Professor D. T. Gwynne-Vaughan.—The Ancestry of the Osmundaceæ.

II.—THE GLACIAL LAKE AGASSIZ.[1] By WARREN UPHAM, A.M., D.Sc., St. Paul, Minn.

DURING the final melting of the North American ice-sheet a glacial lake, held by its barrier in the basin of the Red River and Lake Winnipeg, extended from Lake Traverse, on the west side of Minnesota, northward to the Saskatchewan and Nelson Rivers, and eastward on the international boundary to and somewhat beyond Rainy Lake. It attained thus an area of about 110,000 square miles, exceeding the combined areas of the five great lakes tributary to the St. Lawrence River. This glacial lake, named in 1879 Lake Agassiz, had a southwardly flowing outlet, called the Glacial River Warren, which took the course of the present Minnesota River, joining the Mississippi at Fort Snelling.

Beach ridges of sand and gravel, a few feet high, traced by levelling along about 800 miles of the highest shore of Lake Agassiz, mark its stage of greatest extent, and other similar beaches, at many successive lower levels, record later stages of the lake, reduced in height by erosion of a deep channel along the course of the outflowing river. After the recession of the ice-sheet permitted drainage from the glacial lake north-eastward into Hudson Bay, still lower beaches were formed, until the complete uncovering of the area crossed by the Nelson River reduced Lake Agassiz finally to its present representative, Lake Winnipeg.

In its earliest and highest stage, Lake Agassiz was nearly 200 feet deep above Moorhead and Fargo; a little more than 300 feet deep above Grand Forks and Crookston; about 450 feet above Pembia, St. Vincent, and Emerson; more than 500 feet above the site of the city of Winnipeg; and about 500 and 600 feet respectively above Lakes Manitoba and Winnipeg. The length of Lake Agassiz is estimated to have been nearly 700 miles, and its greatest width more than 200 miles.

Reports on the explorations of this ancient lake have been published by the Geological Surveys of Minnesota, the United States, and Canada. In the present paper the latest explanations are reviewed to account for the northward ascent of its beaches.

[1] Paper read before British Association, Section C (Geology), Winnipeg, 1909.

The highest and earliest beach or shore-line has an ascent of about a foot per mile toward the north-north-east; the lower and later shores ascend less; and the lowest shore, marked by beaches only 60 to 70 feet above Lake Winnipeg, are almost perfectly horizontal. It is thus known that the land was being uplifted differentially while Lake Agassiz existed, and that the uplift was nearly completed before the ice-sheet was wholly melted away.

The chief cause of the uplift is thought to be the unburdening of the land by the removal of the vast weight of the ice-sheet, this part of the earth-crust being restored to equilibrium or isostasy by an inflow of the plastic magma at a great depth within the earth, which took place during the time of departure of the ice.

Measures of the shore erosion and beach accumulation indicate that the duration of Lake Agassiz was only about 1000 years; and from the rate of recession of the Falls of St. Anthony, forming the gorge of the Mississippi River between Fort Snelling and Minneapolis, the length of the Post-Glacial period is estimated to be between 6000 and 10,000 years.

REVIEWS.

I.—An Egyptian Oasis: an account of the Oasis of Kharga in the Libyan Desert, with special reference to its History, Physical Geography, and Water-Supply. By H. J. Llewellyn Beadnell, F.G.S., etc. 8vo; pp. xiv, 248, with 28 pictorial plates and 4 maps and sections. London: John Murray, 1909. Price 10*s.* 6*d.* net.

A VERY interesting account of the "Flowing Wells and Sub-Surface Water in Kharga Oasis", accompanied by map, section, and view of one of the wells, was contributed by Mr. Beadnell to the Geological Magazine for February and March of last year. The author has now published in full his researches on the history and physical features of this extensive and remarkable oasis.

The oases of the Libyan Desert appear to have been inhabited from early prehistoric times, as flint implements of Palæolithic type occur on the margins of the plateaus that border the oases, and also within the depressions. Although at Kharga no natural outflow of water now occurs on the floor of the oasis, the author considers it probable that in those early times there may have been some natural springs, which escaped through fissures and attracted attention. Many ancient wells 120 metres in depth continue to flow now, though for the most part the yield has diminished. It is not known when the flowing wells were first made, but it has been ascertained that during their occupation of the country the Romans largely developed the water-supply, cutting underground tunnels of great length in solid rock with numerous air-shafts in the 'surface-water sandstone'.

As the author dealt with the geological structure of the region in the article before mentioned, we need not further refer to this part of the subject. With regard to the origin of the oasis, he finds no evidence of fluviatile erosion, nor of local subsidence. Tectonic

movements have affected the shape of the ground by bringing rock-masses of varying hardness and composition under the influence of subaerial agents of destruction; and thus deep and broad hollows in the softer strata have been excavated nearly to sea-level out of a plateau that rises in places to an elevation of 400 metres or more. Changes in temperature have facilitated the crumbling of the rocks, but the main agent in erosion is that of the sand-blast.

The Kharga Oasis is described as one of the most windy places in the country, and the sand which is drifted appears to be derived mainly from strata newer than the Middle Eocene, which "are exposed on the surface of the country between the Mediterranean Sea and latitude 29° N." The sands are not wholly siliceous, but contain also grains of white limestone.

The extreme length of the Kharga Oasis is stated to be about 185 kilometres, or 115 miles, and the breadth to vary from 20 to 80 kilometres.

Of particular interest is the evidence, obtained by the author, that the depression had at an early period been the site of an immense lake. He points out that thick deposits of calcareous tufa are found on the escarpments bordering the oasis and on the face of the cliffs. "The tufas frequently contain large numbers of freshwater shells and an abundance of fossil vegetation, and, from the presence of casts of the leaves of such trees as the oak, one is led to refer the deposit to the more humid period which preceded the incoming of the modern desert conditions." These tufas may have been formed on the margin of the lake.

The floor of the depression is occupied by large isolated patches of "horizontal finely-bedded alternations of sand and clay, or more frequently of an intimate mixture of the two", lacustrine strata, probably of Pleistocene age, which have been subjected to considerable erosion. The discovery of fragments of pottery proves "that the lake was contemporaneous with man". It appears to have extended over a distance of 136 kilometres, or 85 miles, and to have attained a height of from 70 to 85 metres above sea-level. It probably "existed well into the historic period", to about 500 B.C., but "when the country became a Roman province, the lake had very much contracted, and probably only existed as a marshy swamp occupying the lower portions of the depression".

In the author's opinion there is good reason to believe that the oasis was inhabited prior to the formation of the lake; and he remarks, "we must not forget the possibility that it was formed by artificial means during one or other of the Egyptian dynasties between 3000 and 1000 B.C." Wells may then have been dug, and the escape of water from a previously untapped artesian basin may have been on a much larger scale than it is now; or it is possible that "If one or other of the porous beds, charged with water under pressure, should, through the action of denudation on the overlying beds, become exposed at the surface, the waters would escape through natural springs in very large quantities". Thus the higher water-bearing strata, known as the 'surface-water sandstone', may have been covered by impervious clays, so as to contain water under

pressure, as is the case with the lower 'artesian-water sandstone' at the present day.

In the articles to which reference has been made, the author dealt with the probable sources of the artesian waters, their saline ingredients, the amount of discharge, etc. In the present work he has amplified the information on the wells and borings, and has given the results of experiments to show the mutual interference of one well or boring on another. The data show that the shutting down of a flowing well or the opening of a closed one may produce a marked effect within an hour, when the distance is more than 500 metres.

The author discusses the drifting of the sands, and the various economic aspects of the Kharga Oasis, adding a few notes on sport and natural history. To geologists, and especially to those interested in the problems of water-supply, the work contains a great deal of important practical as well as scientific information; while to the general reader the story of the wonderful work achieved in ancient times by means of artesian wells and irrigation in the desert regions of Upper Egypt will be found both fascinating and impressive.

II.—Geological Survey of New Zealand.

"THE Geology of the Mikonui Subdivision in North Westland," by Mr. P. G. Morgan, forms the subject of Bulletin No. 6 (New Series), 1908. The country here described borders the Wanganui River and the Tasman Sea to near Hokitika, on the coast of the Southern Island, north-west of Christchurch. The oldest rocks, comprising schists and grauwackes, form an intensely folded and altered complex of sedimentary and igneous rocks, including serpentine. They are grouped as the Arahura Series, and regarded as probably Palæozoic. A newer set of rocks, somewhat less altered and perhaps of Carboniferous age, is known as the Greenland Series, and into this bosses of granite have been intruded. A great gap succeeds, for the next group is Eocene-Oligocene, and includes the local coal-bearing strata, followed by some Miocene deposits. Then come the Glacial drifts of Pliocene and Pleistocene age, and the Recent fluviatile and marine deposits. The various sedimentary formations and the igneous rocks are described in detail.

The physiography of the area, the mountains and snowfields, the rivers, lakes, gorges, hanging-valleys, plains, and other features are also described and illustrated.

The mineral resources appear to be limited; alluvial gold has been obtained in the Totara and Ross districts, and from black sands on the sea-beach, and some auriferous quartz-mining has been carried on. For the most part, however, the metalliferous deposits have not proved to be extensive, the gold placers have largely been worked out, and the coal-mining has not been satisfactory. It is remarked, however, that in respect to water-power Westland is richly gifted.

The work is illustrated by many excellent pictorial views, as well as by neat colour-printed topographical and geological maps and sections.

III.—Brief Notices.

Changes of Level in the Nile Valley.—In an article on "Elevation and Depression in the Nile Valley" (*Cairo Scientific Journal*, April, 1909), Dr. W. F. Hume summarizes the conclusions at which he has arrived as follows:—

1. Elevation due to folding that resulted in fracture (not necessarily accompanied by faulting), and gave rise to the Nile Valley cleft.
2. Depression to at least 250 feet in late Pliocene times, admitting the sea up the Nile Valley at least as far as Sidmant, determining a chain of lakes in the valley, and the accumulation in them of thick deposits of rain-eroded materials.
3. Elevation to at least 600 feet, involving the drainage of the lakes, the cutting back of the cataracts, and the deepening of the river valley.

Cotteswold Naturalists' Field Club.—The Proceedings, vol. xvi, pt. iii, June, 1909, contains a short article "On the occurrence of *Chara*-nucules in the Forest Marble of Tarlton, near Kemble, Gloucestershire", by Mr. Charles Upton, who names the new species *Chara lævigata*. Mr. T. S. Ellis deals with the origin of "The Lower Severn Valley, River, and Estuary from the Warwickshire Avon to the Bristol Avon", and combats the notion that the Lower Severn was cut backwards so as to behead a stream which was formerly connected with the river-system of the Thames. Mr. L. Richardson contributes a "Note on *Pollicipes aalensis*, Richardson" (described in the Geological Magazine for August, 1908), and also a short article on "The Dorset and Hampshire Coasts, with particular reference to the Forest Marble Beds near Langton Herring".

CORRESPONDENCE.

THE OLD AND NEW THEORIES OF IGNEOUS ROCKS.

Sir,—Your review of Mr. Harker's *Natural History of Igneous Rocks* inferentially gives judgment against my two 1903 papers in the Geological Magazine on all points. So I crave a word of explanation.

After General McMahon's reply, in November, 1903, to my "Crystallization of Granite" appeared, I learned to my regret how ill he was, and that the controversy had troubled him. I at once wrote to express my regret, and received a most friendly answer. There, so far as the Magazine is concerned, the matter dropped, leaving me apparently crushed.

I subsequently submitted my paper to two physicists and to Dr. Sorby, with a view to clearing up outstanding doubts, if possible. Dr. Sorby gave me a general permission to use his letters, and I got all the leave I asked for from the physicists. I subsequently reviewed the whole controversy in the Transactions of the Devonshire Association. The dispute thus remains at a loose end, with no attempt by the petrologists to settle it.

To give you an idea how loose the ends are, I may say that in October, 1903, a physicist wrote as follows:—"My best thanks for the copy of your paper and letter accompanying it. I should not wonder if the petrologists are all adrift."

I see that your reviewer considers that the old doctrine of the permeability of rocks by overhead waters has been finally disposed of. Now geologists always rely on the explosive or expansive action